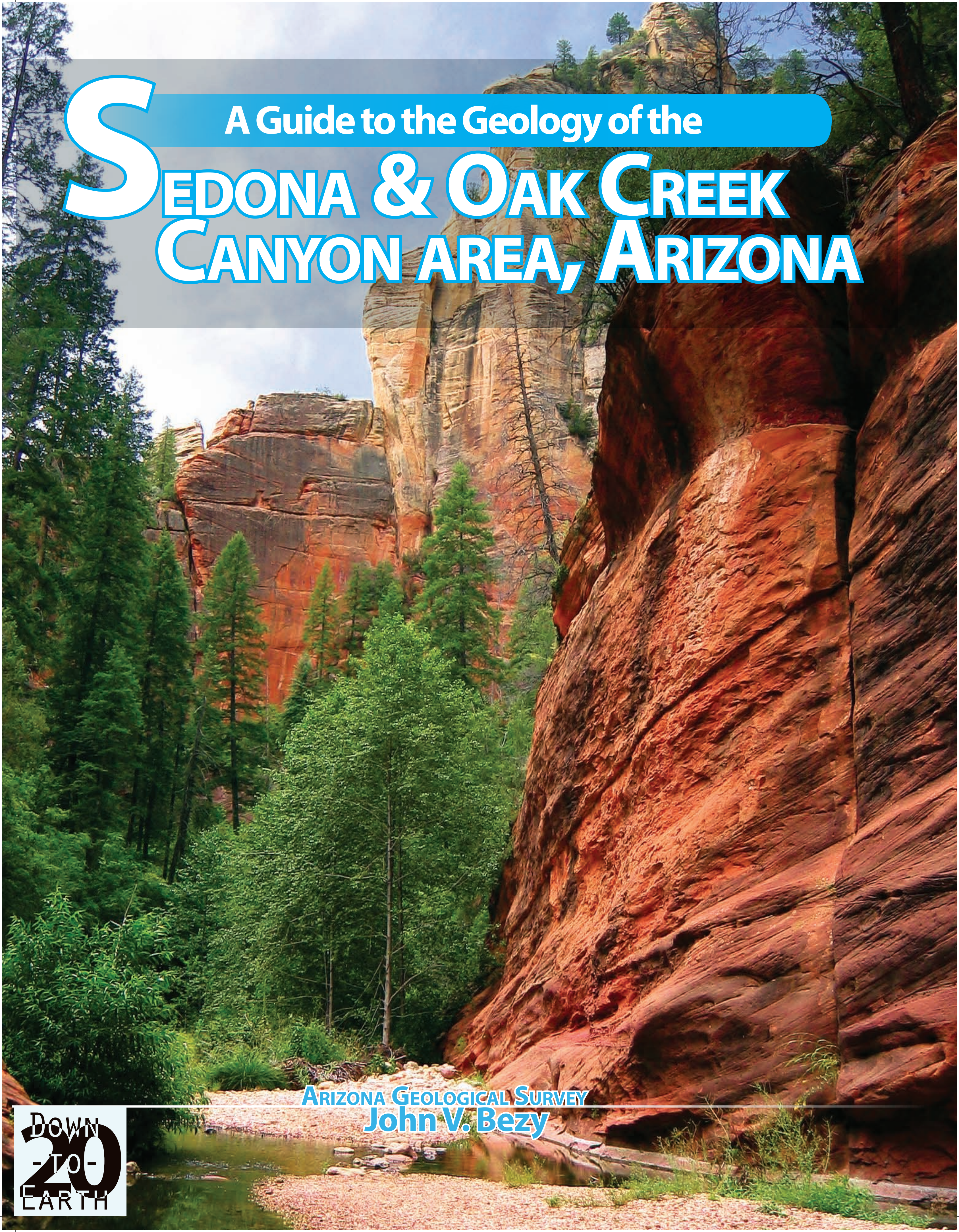
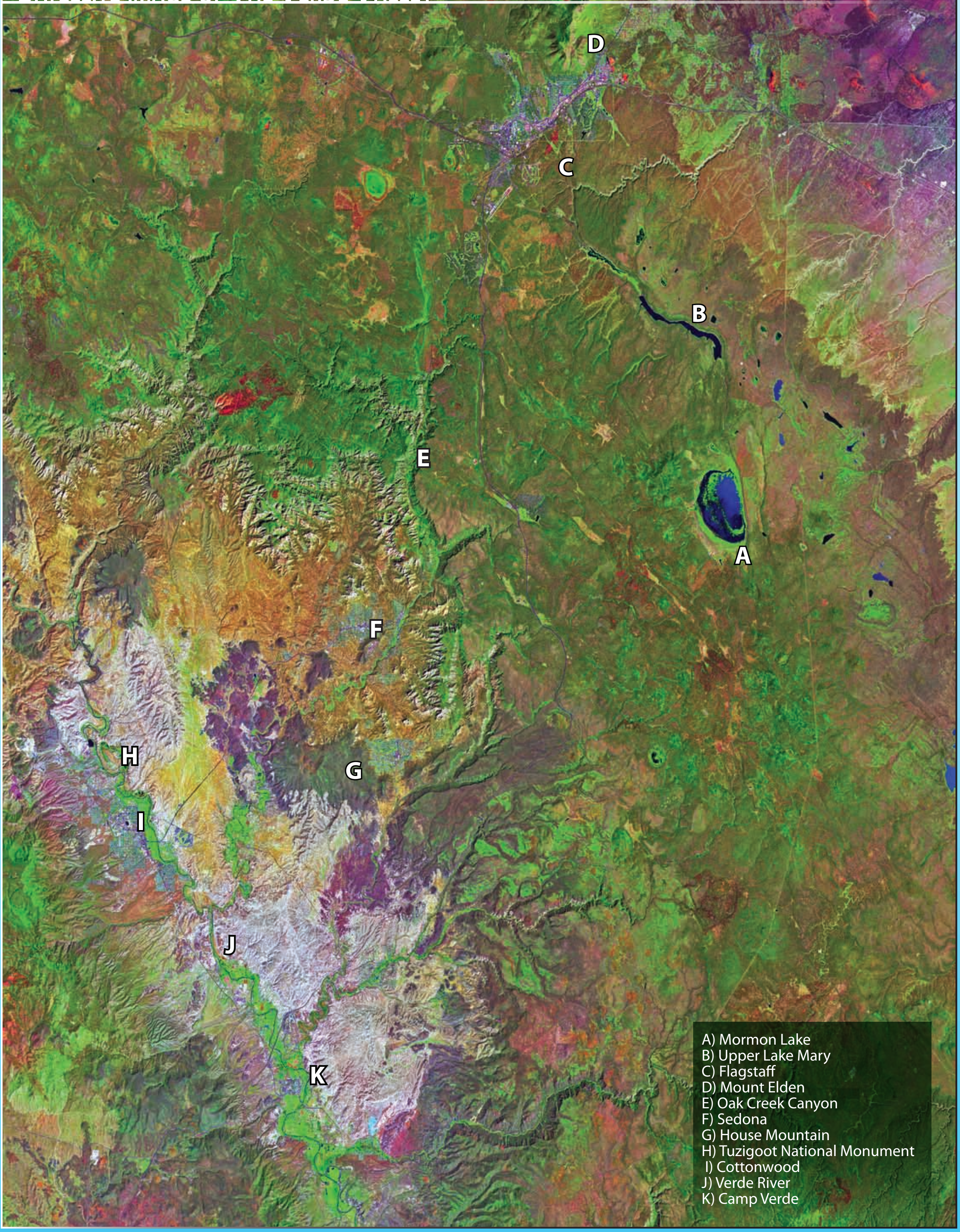
A Guide to the Geology of the SEDONA & OAK CREEK CANYON AREA, ARIZONA



ARIZONA GEOLOGICAL SURVEY
John V. Bezy

DOWN-TO-EARTH 20

Satellite image of The Verde Valley



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John V. Bezy

Arizona Geological Survey

Down-to-Earth 20

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John Bezy unless otherwise noted
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Dr. Larry D. Fellows

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Dr. John Dohrenwend graciously granted permission to use his satellite images in this publication. Poster sized satellite image maps (1:100,000 scale) of the Sedona-Oak Creek region may be ordered from John Dohrenwend, P.O. Box 1467, Moab Utah 84532--1467, phone (866) 230-8941, Email: dohrenwend@rkymtnhi.com.

Thanks are extended to Superintendent Kathy Davis and Park Ranger Dennis Casper for providing a satellite image of Tuzigoot National Monument, and to the Park Manager of Slide Rock State Park for permitting the use of Figure 3.1.

Mr. Arnie Bermudez deserves special thanks for the many hours he devoted to designing this publication.

This publication would not have been possible without the professional support of Drs. Lee Allison (Director, Arizona Geological Survey) and Mike Conway (Geologic Extension Service, Arizona Geological Survey).

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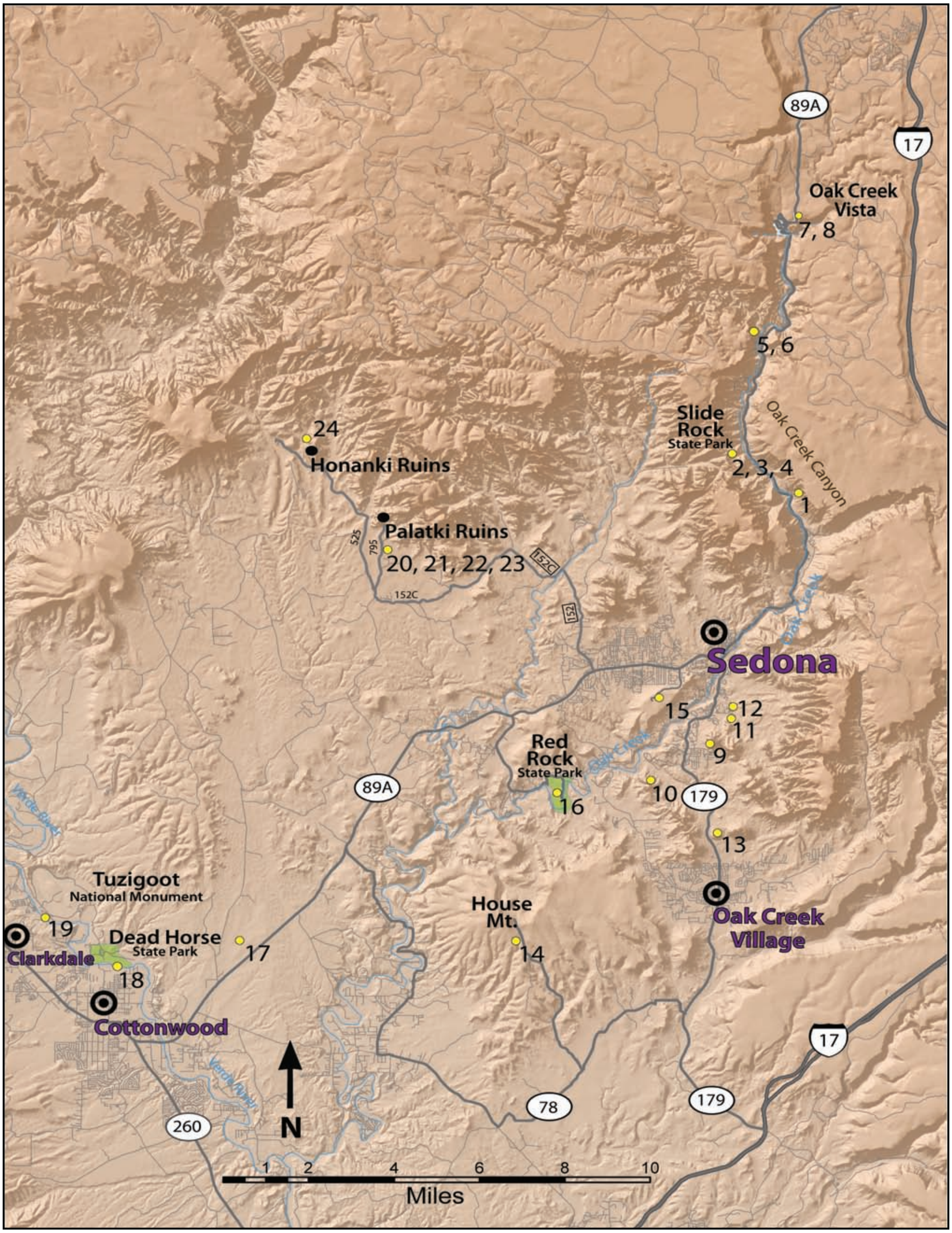


Figure A. Geologic features and access roads in the Sedona-Oak Creek Area (numbered 1-24).

The Sedona-Oak Creek Canyon area offers some of the most unique and spectacular geologic features in northern Arizona. Because of the relatively sparse vegetation most of these features are easy to recognize and photograph.

Some of these geologic features are common on the Colorado Plateau of northern Arizona, western Colorado, southern Utah, and northeastern New Mexico. Others occur in many other parts of the American Southwest.

This booklet is your field guide to the geology of this magnificent landscape of red rock pinnacles, buttes, mesas and canyons. All of the geologic features described in the text can be reached by short walks from Highways 89A and 79, Road 78, and from U.S. Forest Service roads. This booklet is written for the visitor who has an interest in geology, but who may not have had formal training in the subject. It may also help assure that the visiting geologist does not overlook some of the features described.

To set the stage, I have briefly described the area's geologic setting and history. In the following pages, emphasis is given to the description of geologic features that are common in the landscape. Precise directions to each feature are provided in the text.

Locations of the geologic features and access roads and trails are shown on Figure A. More detailed locations are provided in the text as needed. All of the roads recommended for use can be driven with any vehicle of moderate clearance. Drainages are subject to flash flooding during periods of heavy rainfall and should be crossed with caution. Restaurants, gasoline, information on road conditions, and emergency services are available in Sedona, Cottonwood, and the Village of Oak Creek.

Another purpose of this guide is to provide the reader with an understanding of the dynamic processes that have shaped this exceptional landscape. You will encounter many of the features discussed in the text again and again as you continue to explore the Southwest. I hope that your experience in the Sedona-Oak Creek Canyon area will enhance the pleasure of those explorations.

The Supai Group has been divided into formations by some geologists. For the purposes of this non-technical publication the traditional name Supai Group will be used for all rock units between the Coconino Sandstone and the Redwall Limestone in the Sedona-Oak Creek Canyon area.

Figure B The Colorado Plateau, the Transition Zone, and the Basin and Range Province of north-central Arizona.

General Geology of the Sedona-Oak Creek Canyon Area

Figure C The Mogollon Rim north of Sedona, Arizona.

The Sedona-Oak Creek Canyon area is situated in a Transition Zone between two great geologic provinces: the Colorado Plateau and the Basin and Range (Figure B.) The Colorado Plateau, a 130,000-square-mile region of vast plains, high mesas, buttes, deep canyons, volcanic fields and isolated mountains clusters, is built of thousands of feet of generally horizontal sandstone, shale, limestone strata and basalt flows. In north-central Arizona, the southern margin of the Colorado Plateau is the Mogollon Rim, that line of spectacular cliffs north of Sedona (Figure C).

The sedimentary and volcanic rock layers that form this part of the Colorado Plateau are beautifully exposed in the Mogollon Rim north of Sedona. In ascending order they are: the Supai Group, the Coconino Sandstone, the Toroweap and Kaibab Formations, and the basalts of the San Francisco volcanic field. Basalts of the Mormon Mountain volcanic field cap the Mogollon Rim to the west of Sedona. South of Sedona, are dark-colored basalts of the House Mountain volcano and the white sedimentary layers of the Verde Formation (Figures D).

For most of its geologic history this part of Arizona was a low-lying region where sediment was deposited and preserved to form the layers of red and buff rocks exposed in the Sedona-Oak Creek Canyon region. The oldest of these sedimentary rock units that is exposed throughout the region is the Supai Group, deposited 310 to 270 million years ago (some sources say that the Supai Formation is 270-220 million years old). During this time the Sedona-Oak Creek Canyon region was a nearly flat, subtropical desert coastal plain bordered by shallow seas, at the latitude of present-day Central America. Some sandstones and conglomerates were deposited by wet-weather streams. Other sandstones were deltas, beaches, or desert dunes. Mudstones and limestones accumulated in lagoons and the sea. The sea advanced and retreated across this coastal plain numerous times, leaving alternating layers of terrestrial and marine sedimentary rocks. Arid conditions limited life on land and fossils are mainly from species that lived in the sea.

The upper part of the Supai Group was deposited 275 to 270 million years ago (Permian time) as extensive sand seas on an arid coastal plain. At times the dune sand was reworked by the tides and spread along beaches, as occurs in coastal portions of the Sahara and Namib Deserts today. These massive wind-deposited sandstones, well-cemented by calcium carbonate and silica, are resistant to erosion and form most of the orange-red cliffs and buttes around Sedona, such as Bell Rock, Courthouse Rock, Coffee Pot Rock and Cathedral Rock.

The Coconino Sandstone (270 to 265 million years old, late Permian time) forms the tall, nearly vertical cream-colored cliffs above the Supai Group. Deposited as massive sand dunes, similar to those found in the great sand seas of the Sahara and Saudi Arabia, this sandstone represents an arid, inland environment far removed from the sea. The Coconino Sandstone and the underlying upper Supai Group contain very few fossils due to harsh desert conditions.

The Toroweap Formation (about 265 to 262 million years old,

late Permian time) caps the Coconino Sandstone and represents a return to an arid, coastal environment. This thick sandstone was once beach and shallow coastal sand. It contains beds of gypsum that accumulated as high temperatures evaporated seawater from saturated desert soils.

Distinctive buff-colored cliffs above the Toroweap Formation mark the Kaibab Formation (about 262 to 255 million years ago, late Permian time). This rock unit consists of silty limestone and dolostone, and sandstone and siltstone cemented by calcium carbonate. The Kaibab Formation was deposited in shallow seas and on an arid coastal plain.

Dark-colored rim rock capping the plateau is basalt from the San Francisco Volcanic Field (Figure B, SF). Beginning about 6 million years ago, magma (molten rock) from deep inside the Earth migrated upward along old fractures and flowed onto the plateau surface as lava. Eruptions continued during the period 3 million to 1000 years ago. The basalt at Oak Creek Vista is about 6 million years old. The basalt capping the cliffs to the east and southeast of Sedona are old lava flows from the older (3 million to 15 million years ago) Mormon Mountain Volcanic Field (Figure B, MM).

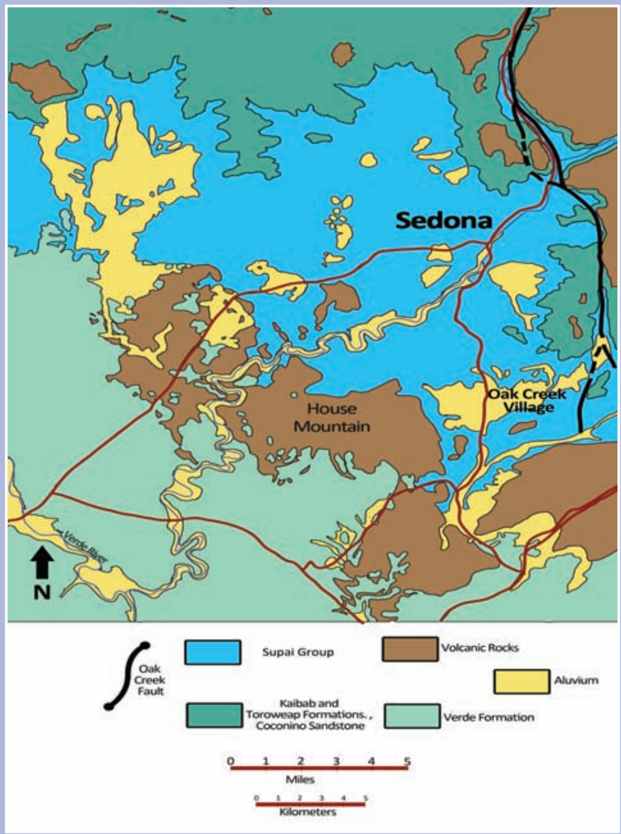


Figure D Geologic map of the Sedona-Oak Creek area.

The contact between these plateau-capping volcanic rocks and the underlying Kaibab Formation marks a time gap in the geologic record of nearly 240 million years, years not represented by rock at this locality. The uplift of the Mogollon Highlands in central Arizona about 60 million years ago tilted the entire sequence of Paleozoic and Mesozoic strata in the Sedona-Oak Creek Canyon region to the north. At this time, rivers flowed from the higher Mogollon Highlands across the Sedona-Oak Creek Canyon region toward lowlands to the north. Erosion by these rivers removed the Mesozoic strata that once existed here and left deposits of sand and pebbles collectively called "rim gravels' because they are found along the Mogollon Rim.

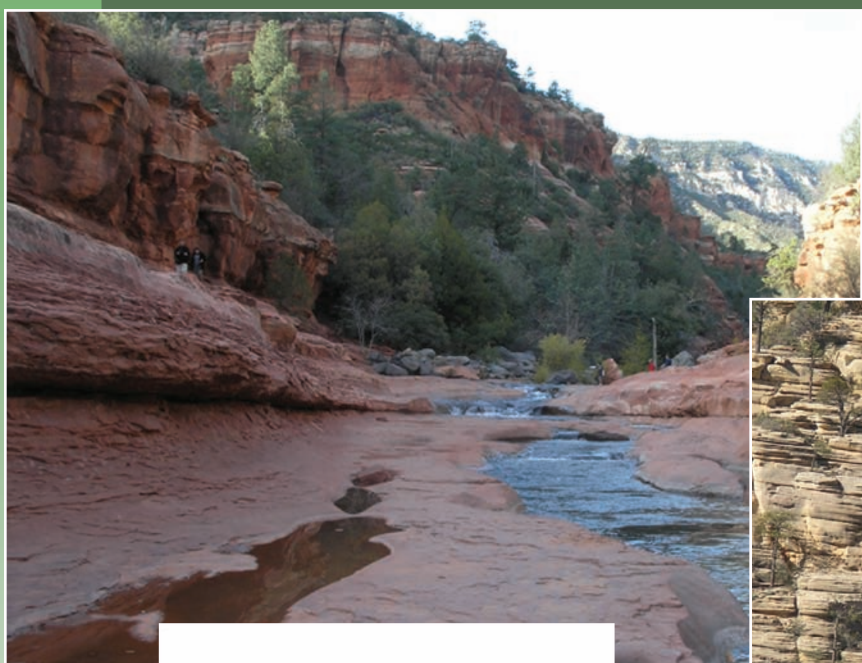
Between 35 and 15 million years ago, the crustal rocks of western North America were stretched, thinned, and broken in blocks along steep cracks, called faults. This crustal extension led to the collapse of the Mogollon Highlands. This collapse, combined with thousands of feet of uplift of the Colorado Plateau, triggered a drainage reversal in the Sedona-Oak Creek Canyon region. Streams now flowed southward from the southern rim of the Colorado Plateau and the Oak Creek and Verde River system slowly developed. Today, continued erosion is wearing back the cliffs of Pennsylvanian, Permian, and Neogene rocks north of Sedona. This northward retreating line of cliffs, the Mogollon Rim, is the southern edge of the Colorado Plateau in Arizona.

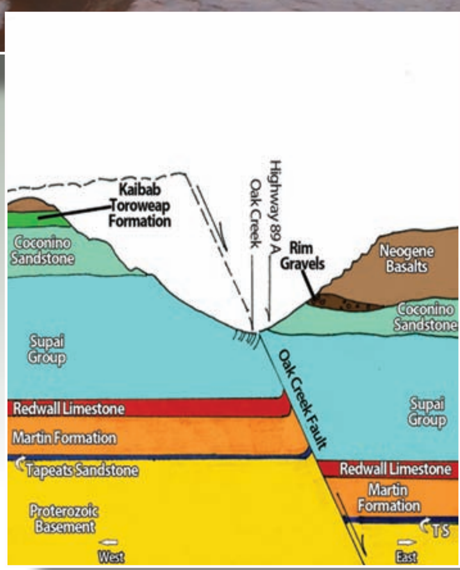
Continued stretching of the crust in the Sedona-Oak Creek Canyon region caused one of these blocks to subside thousands of feet relative to other blocks, forming the deep basin now occupied by the Verde River. A high-standing block was eroded to form Mingus Mountain southeast of the Verde Valley. About 10 million years ago molten rock (called magma inside the earth and lava when it erupts onto the surface) migrated upward along faults and flowed onto the land surface. A series of these lava flows south of present-day Sedona built the House Mountain shield volcano. During this same time period, faulting and lava flows dammed the Verde River. More than 275 feet (900 m) of sediment accumulated as limestones, mudstones, sandstones, gypsum, and conglomerates in these dry-climate lakes and form the Verde Formation that is exposed along the modern Verde River valley.

The early Verde River, lower Oak Creek, and some of their tributaries flowed in looping meanders across broad floodplains, much like the Mississippi River does today. During the last 6 million years regional uplift and reactivation of faults caused these streams to downcut their channels into underlying sediments and, eventually, bedrock. This downcutting preserved the sinuous flow pattern of ancient streams in many canyons of the modern landscape. Other canyons have straight courses because they were cut by streams eroding the pulverized zones of rock along faults. For example, several episodes of vertical movement along the Oak Creek Fault produced a zone of shattered and powdered rock. Oak Creek excavated this shatter zone as it extended its headwaters into the Mogollon Rim, producing Oak Creek Canyon. Later movement along this fault triggered outpourings of lava that filled the canyon. The lava cooled to form basalts that were offset as movement along the fault continued.

Today, weathering, rockfalls and landslides, and erosion by the Verde River-Oak Creek drainages continue to enlarge Oak Creek Canyon and wear back the Mogollon Rim. Red rock mesas and buttes surrounding Sedona are monuments to the power of these processes and record the diverse landscapes that once existed in this part of North America.

Geologic Features Along Highway 89A North of Sedona





FEATURE 1

Location: Follow Highway 89A north from Sedona to the Encinoso Picnic Area. The talus is on the canyon wall on the right (east) side of the highway.

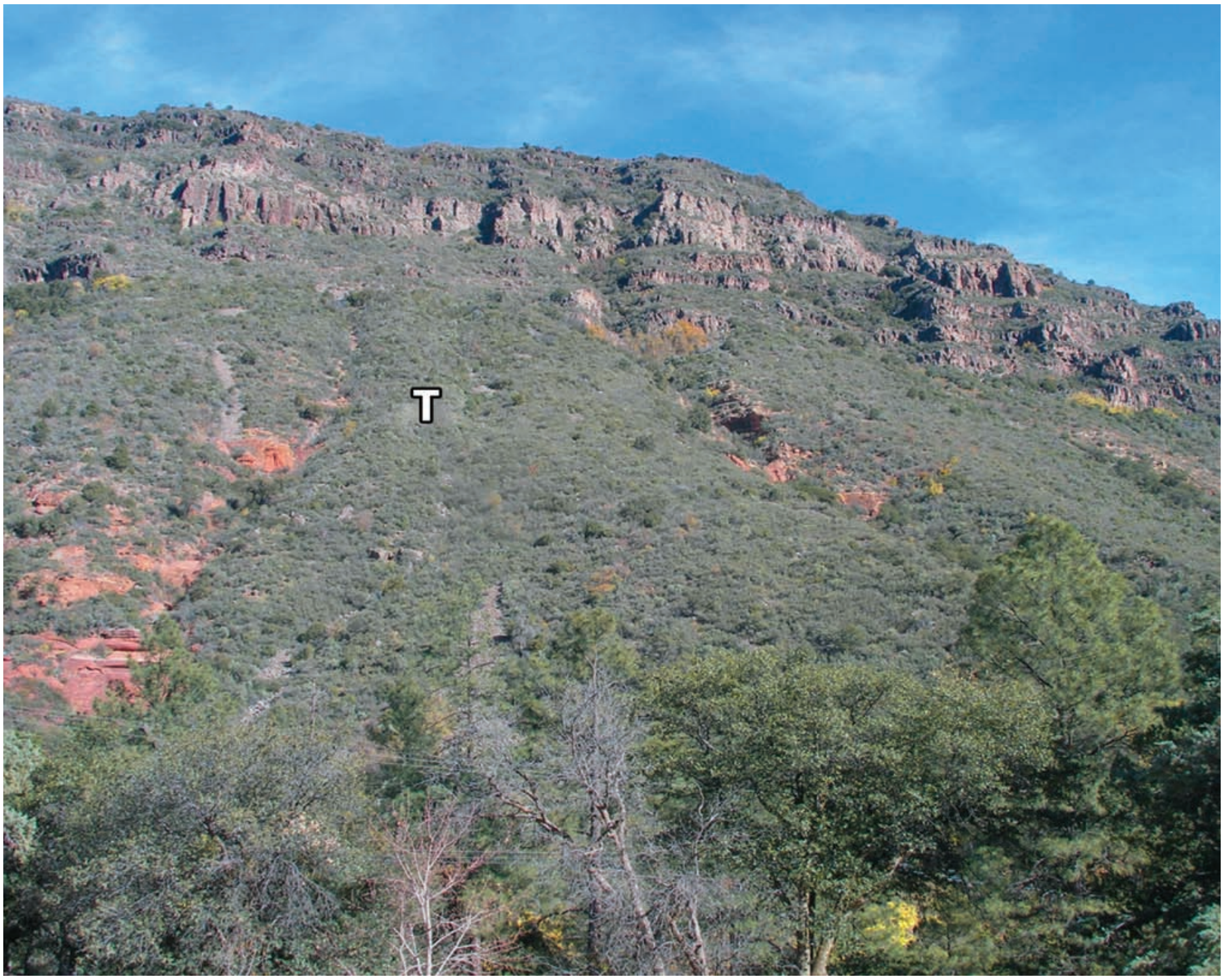


Figure1.1 Talus (T) east of Encinoso Picnic Area, Oak Creek Canyon.

Talus, rock rubble mantling the steep slopes in Figure 1.1, T, is a common landform in deserts and high mountains. Such rock debris covers the walls of Oak Creek Canyon for most of its extent. Wedging by ice and plant roots, decomposition and other types of weathering processes loosen rock fragments in the basalt cliff above the talus. When dislodged, these chunks fall to the slope below and break into angular pieces. In time, this slope accumulates an apron of rock debris. Freshly fallen rock lacks the mineral coating called rock varnish (Feature 6) and contrasts sharply with the dark color of older debris.

Talus is the product of weathering followed by rock movement due to gravity.

Landslides are also common in Oak Creek Canyon. They result when an entire section of the canyon wall fails, usually because the rock has become saturated with moisture from heavy rains or snowmelt. Wildfires contribute to landslides by destroying vegetative cover that stabilizes loose rock debris on steep slopes.

Talus is the product of weathering followed by rock movement due to gravity. Both processes, together with landsliding, play a major role in canyon widening. The rock debris eventually reaches Oak Creek where, overtime, it is broken into small fragments and flushed from the canyon by flash floods.

FEATURE 2

Location: Follow Highway 89A north from Sedona to Slide Rock State Park. The Supai Group is exposed in the cliffs west of the parking area.

The orange-and buff-colored cliffs in Figure 2.1 (SG) comprise the Supai Group, deposited between 370 and 210 million years ago (Permian time). These sandstones, siltstones, mudstones, limestones, dolostones, and conglomerates form most of the colorful cliffs, mesas, and buttes around Sedona. These layers were deposited as sediment on an arid coastal plain, or in shallow seas that advanced and retreated numerous times across the desert coastline.

Sandstones, limestones, dolostones, and conglomerates are hard, resistant to weathering and erosion in Arizona's arid climate, and form vertical cliffs. Siltstones and mudstones are softer and weather and erode into slopes. Most of these layers consist of rock fragments worn from ancient mountain ranges. Limestones and dolostones, however, were precipitated directly from sea water. The individual fragments that make up these layers are bonded together by calcium carbonate, silica, or iron.

The red and orange color of the rock cliffs is due to minute quantities of iron oxide. As the rocks were being deposited, groundwater carrying dissolved iron slowly percolated through the accumulating sediments. In time, each grain of sand, silt, or clay became coated with a film of iron that oxidized (just as an iron tool rusts), imparting red and orange hues to the cliffs of today's landscape.

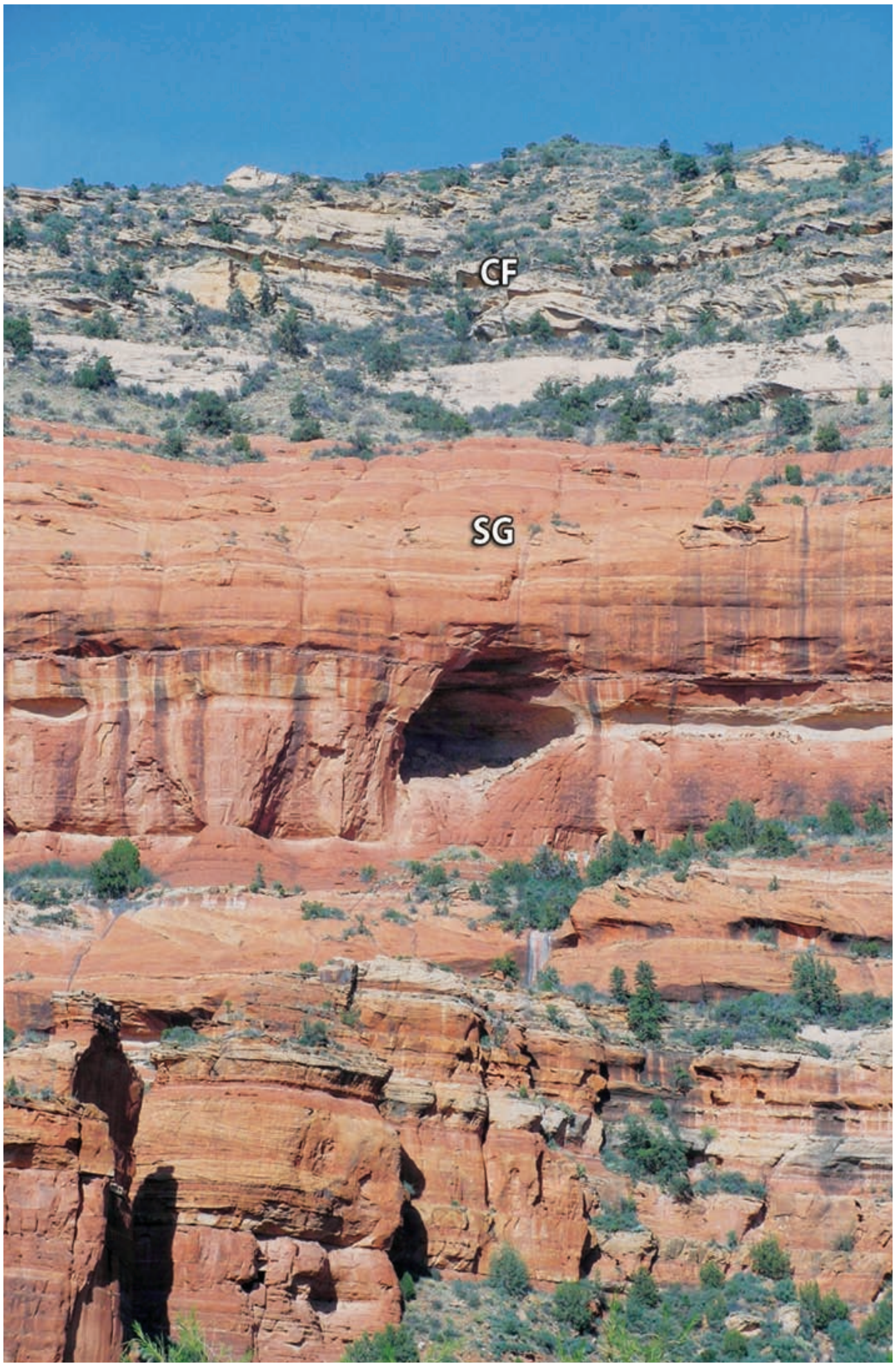


Figure 2.1 The Supai Group (SG) and overlying Coconino Formation (CF) at Slide Rock State Park.

The Supai Group in Arizona is of particular economic interest because it contains deposits of salt and potash. These minerals accumulated as sea water was evaporated from arid, Permian-age lagoons and mud flats. In eastern Arizona, caverns leached from thick beds of Supai Group salt provide storage for liquefied petroleum gas (LPG). Wells drilled into the Supai Group have produced carbon dioxide, helium, nitrogen gases and traces of petroleum.

FEATURE 3

Location: Follow Highway 89A north from Sedona to Slide Rock State Park.

Normal Fault

Oak Creek Canyon was eroded by Oak Creek along a fault. A fault is a fracture in the brittle rocks of the Earth's crust along which movement has occurred. The direction and amount of movement may be revealed by the displacement of rock layers on opposite sides of the fault. In this case (Figure 3.1), rocks east of the Oak Creek Fault have moved down relative to the rocks west of the fault. Such a fault is called a normal fault.

Beginning about 65 to 75 million years ago, western North America was subjected to intense horizontal compression. This stress deformed, and then fractured the Permian and Pennsylvanian rock layers north of Sedona, creating the Oak Creek Fault. During this initial episode of slippage the rocks east of the fault were uplifted about 600 ft. (183m.) Running water cut a canyon along the zone of pulverized rock along the fault. Over time erosion wore down the uplifted block of rock east of the fault by removing the Kaibab, Toroweap, and upper Coconino Formations. Nearly vertical layers of once-horizontal rock exposed in the bed of Oak Creek (Figure 3.2, A) are testimony to the frictional drag that occurred during fault movement.

About 25 million years ago the crustal rocks of western North America began to be stretched and thinned. In northern Arizona this extension triggered a series of basalt flows approximately 8 to 6 million years ago that filled the original Oak Creek Canyon. Continued stretching re-activated the Oak Creek Fault for a distance of nearly 30 miles (48 km.). During this later period of slippage rock east of the fault moved down relative to the rocks west of the fault. Oak Creek, again following the zone of shattered rock along the fault, extended its course northward by headward erosion and excavated the modern Oak Creek Canyon.

Although fault-aligned canyons are common features of the landscape, they are particularly spectacular on and along the margins of the Colorado Plateau. Here thousands of feet of uplift have enhanced the cutting power of streams that flow from the Plateau to neighboring lowlands. Where this power is channeled along weak zones of fault-pulverized rock, streams such as Oak Creek have cut hundreds of chasms into the colorful strata of the Plateau.

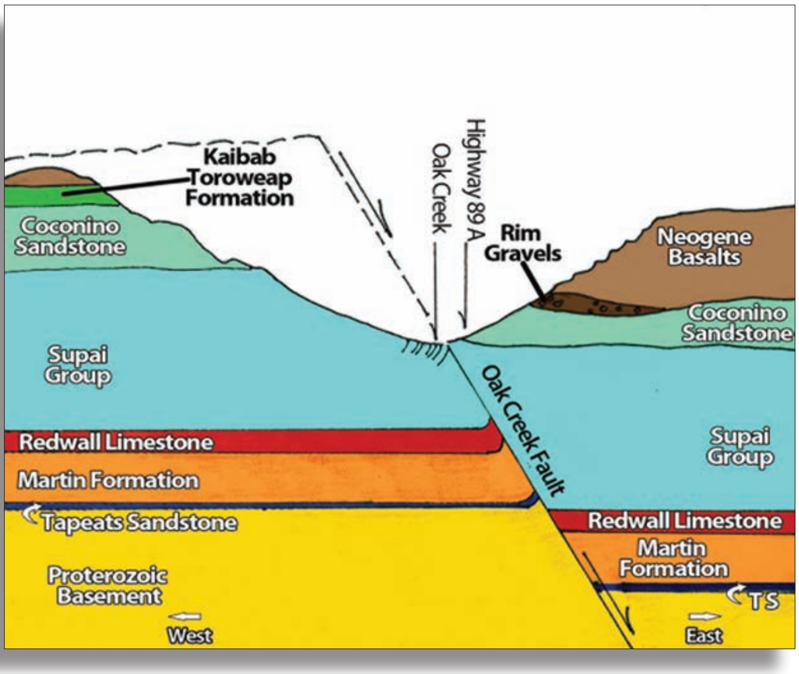


Figure 3.1 East- west cross-section of Oak Creek Canyon at Slide Rock State Park, showing the vertical displacement of strata. Note that the sequence of rock layers is lower on the east wall of Oak Creek Canyon (after Paul Lindberg) (Courtesy Sliderock State Park).

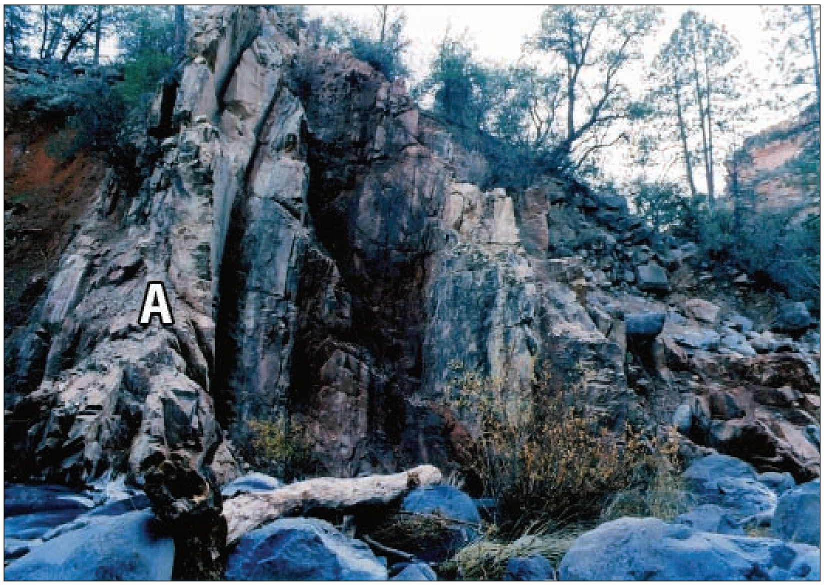


Figure 3.2 Nearly vertical bed of once-horizonal rock in the bed of Oak Creek, near Bootlegger Campground (photo by Dr. Larry D. Fellows).

FEATURE 4

Location: : Follow Highway 89A north from Sedona to Slide Rock State Park. Hike the park trail for about 0.5 mi. (800 meters) to the bed of Oak Creek Canyon.

Figure 4.1 Channel cut into the sandstone floor of Oak Creek Canyon during times of flash-flooding.

Oak Creek acts as a geological conveyor belt, moving rock fragments along the floor of Oak Creek Canyon to the broad valley where Sedona is located. These rock fragments, flushed down the canyon by torrential flash floods, cut this channel into the relatively soft sandstone of the Supai Group (Figure 4.1).

During the summer thunderstorms and when hurricanes bring heavy fall rains to Arizona, Oak Creek is transformed into a swift and powerful torrent that moves vast quantities of boulders, cobbles, pebbles and sand along its bed. Much of this debris is basalt talus swept into the rising current from the lower canyon slopes. Being harder than the sandstone in the floor of the canyon, the basalt rock debris cuts the bed of Oak Creek deeper with each flood. As the flood waters slow and gradually lose their power to move large rock fragments, debris is temporarily deposited in the stream bed until the next flood sweeps it farther along its journey to the sea.

The flash-flood transport of loose rock fed into streams by landslides and rockfalls (Feature 1) is the principal process for wearing down mountain ranges and high plateaus and filling adjacent lowlands with sediment.

FEATURE 5

Location: Drive Highway 89A to the West Fork of Oak Creek picnic area. Hike the Call of the Canyon trail for about 0.5 miles (800 m).

The thick, cream-colored rock in the cliffs along this trail is the Coconino Sandstone (Figure 5.1). This sandstone is composed of curving beds that lie at a great variety of angles. Many beds curve in long, parallel arcs that are cut off by sets of similar layers lying at different angles. This complex layering, called cross bedding, is the interior structure of ancient sand dunes.

Extreme aridity and abundant sand during Permian time (about 265 million years ago) permitted strong winds to accumulate massive sand dunes, similar perhaps to those in the great sand seas of the Sahara Desert and Saudi Arabia. As dunes migrate, sand is removed from the windward side, blown over the crest, to slide down the leeward slope—forming inclined layers. When dunes merge and shift, their interior structures are superposed, producing a patchwork of cross strata oriented in a variety of directions.

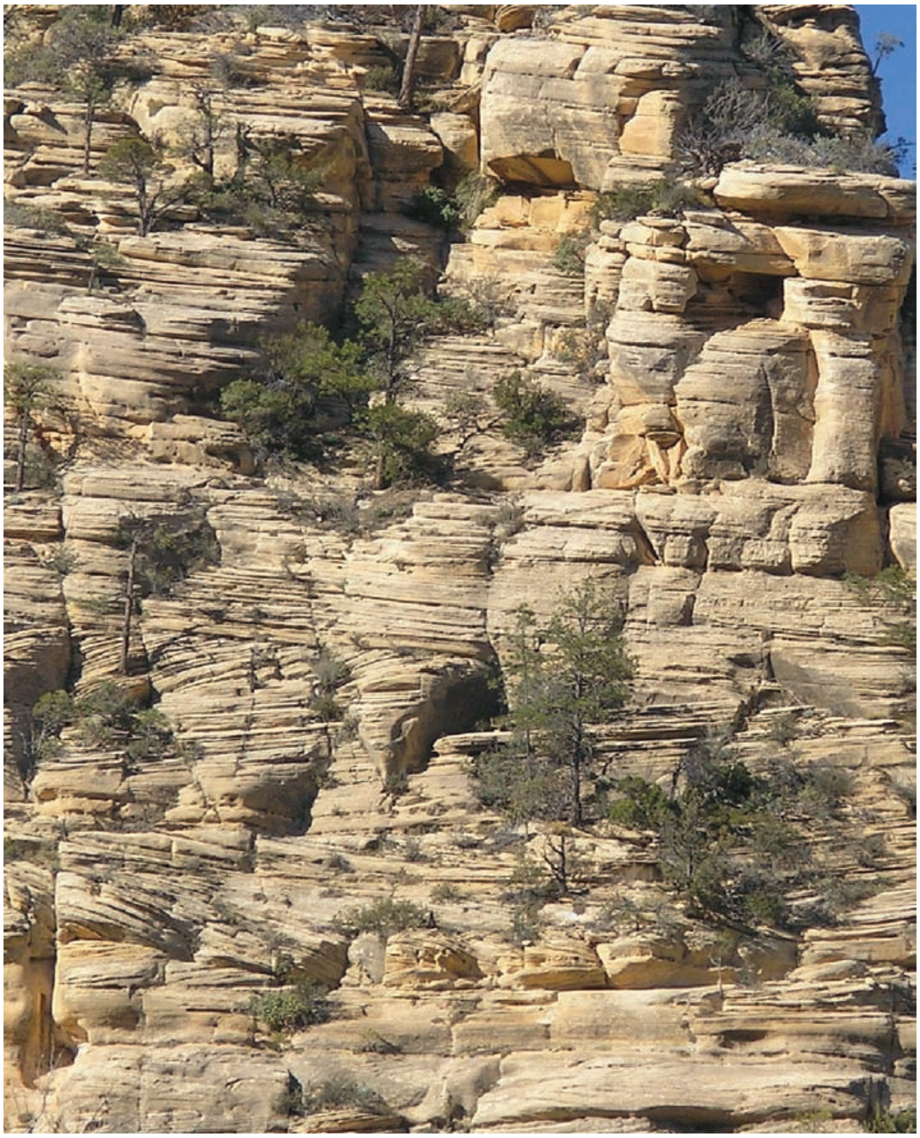


Figure 5.1 Cross bedding in Coconino Sandstone along the Call of the Canyon trail, West Fork of Oak Creek.

The individual grains of quartz sand that make up the Coconino Sandstone are well rounded, of uniform size, and have surfaces that are pitted by innumerable collisions with other sand grains. These are typical characteristics of sand particles that have been transported by the wind. Over time, the grains were cemented together by calcium carbonate and silica carried by percolating groundwater, and the dunes were hardened into sandstone.

Evidence of life in these Permian dunes is limited to fossil footprints of insects, scorpions and reptiles. Fossil plants have not been found.

The Coconino Sandstone extends for about 32,000 square miles (about 8290 square kilometers) in northern Arizona and southern Utah. It forms vertical cliffs where it is exposed in the walls of the Grand Canyon, Oak Creek Canyon, and many smaller gorges. The open spaces between the individual grains of the Coconino Sandstone make it a major source of groundwater.

The Navajo Sandstone of Zion National Park, the Entrada Sandstone of Arches National Park, the DeChelly Sandstone (an equivalent of the Coconino Sandstone) of Canyon de Chelly, and the Wingate Sandstone of Canyonlands National Park are other eolian or wind-deposited sandstones that add grandeur to the Colorado Plateau.

FEATURE 6

Location: Drive Highway 89A to the West Fork picnic area. Hike the Call of the Canyon trail for about a mile (1.61 km); rock varnish is common along the canyon walls of the West Fork of Oak Creek.

Figure 6.1 Rock varnish and lichens on Coconino Sandstone rock face, Call of the CanyonTrail, West Fork of Oak Creek.

The dark-brown- to black-colored substance on the surface of the Coconino Sandstone in Figures 6.1 and 6.2 is rock varnish. This mineral patina masks the true color of the sandstone, which is white to light tan. Rock varnish develops best on rocks that are reasonably hard. Sandstone, basalt, and many metamorphic rocks are commonly well varnished, whereas siltstone and shale disintegrate too rapidly to develop and retain such a coating.

Rock varnish consists of thin layers (typically less than one hundredth of an inch [0.25 mm]) thick of clay minerals stained by high concentrations of iron and manganese oxides. The clay minerals settle as dust from the atmosphere. Manganese, also derived from windborne dust and rain, produces a black to dark-brown coloration of surfaces exposed to air. Many sandstone cliffs in the Southwest contain long streaks of rock varnish. These mineral streaks develop in places where films of iron- and manganese-rich water from rains or snowmelt frequently run down cliff faces. When the water evaporates the minerals are deposited on the rock surface.

Micro-colonies of lichens and bacteria inhabit the varnish and oxidize the manganese. They anchor themselves to rock surfaces with the clay particles, which provide protection against extremes in temperature and humidity. In the process, the manganese becomes attached firmly to the clay and darkens it. Each time the rock surface is wetted by rain, more manganese and clay are added to sustain the slowly growing colony. Such colonies thrive where the rock acidity is neutral and the surface is so nutrient poor that competing colonies of lichens and mosses cannot survive.

Even though older surfaces tend to be more heavily varnished and darker than younger surfaces, scientists are unable to use rock varnish as a tool for determining

FEATURE 6 (continued)

Location: Drive Highway 89A to the West Fork picnic area. Hike the Call of the Canyon trail for about a mile (1.61 km); rock varnish is common along the canyon walls of the West Fork of Oak Creek.

Figure 6.2 Streaks of rock varnish on a cliff of Coconino Sandstone, Call of the Canyon trail, West Fork of Oak Creek.

the exact age of the rock. The rate at which rock varnish forms is not constant because it is affected by many variables, such as climatic change, wind abrasion, biological competition, and abundance of manganese. Some researchers believe that the clay and manganese content of the rock varnish reflects past climatic conditions. Because some varnished surfaces may be many thousands of years old, they could reveal information about climatic change that took placed repeatedly during the Ice Age and in the past 10,000 years.

Well-varnished surfaces have a dull luster that causes entire hillsides to glisten in intense desert sunlight. This mineral coating gives the landscape its warm tones of brown and ebony, commonly masking colorful bedrock below. All of the Earth's deserts have varnished rocks, but in the Southwest these surfaces provoke even greater interest because of their archaeological importance. At innumerable locations prehistoric Indians etched petroglyphs (rock drawings) through the mineral skin to the fresh rock below. Today these symbols are being re-varnished as the process continues.

FEATURE 7

Location: : Highway 89A, Oak Creek Vista. It is best to view these formations from this overlook. Along Highway 89A they are crushed and pulverized by repeated movement of the Oak Creek Fault and there are few safe parking areas.

Figure 7.1 The Kaibab (K) and Toroweap (T) Formations viewed from Oak Creek Vista, Highway 89A.

The buff-colored Kaibab Formation (Figure 7.1, K) consists of horizontal layers of silty limestone and dolostone, and siltstone and sandstone cemented by calcium carbonate. The underlying, reddish-colored Toroweap Formation (T) is cross-bedded sandstone in the cliffs of Oak Creek Canyon, changing to siltstone and gypsum at other locations. Limestone and dolostone are carbonate rocks that are composed of calcium carbonate and calcium-magnesium carbonate, respectively. The erosion-resistant limestone and dolostone form massive cliffs: the less resistant siltstone and sandstone weather and erode back into recesses that shelter the cliff dwellings of early Indian residents of this region. Red and white chert nodules (a form of silica consisting of minute crystals) are common throughout the formation. Fossils of brachiopods, cephalopods, and sponges are abundant in the limestone and dolostone.

The Kaibab and Toroweap Formations were deposited in shallow seas and on arid coastal plains about 265 to 255 million years ago. The sea advanced and retreated across these coastal plains numerous times. The limestone in the Kaibab formed in shallow seawater; the dolostone precipitated from calm, shallow seawater; silty and sandy dolostones originated along the shore and in mud flats; sandstone and siltstone were deposited on the coastal plains by streams. Some of the sandstones in the Kaibab and Toroweap Formations were beach and dune sand. Gypsum, a calcium sulfate salt; formed were seawater was evaporated from soils.

The Kaibab and Toroweap Formations form sheer canyon walls and the resistant caprock on high plateaus and buttes in this part of Arizona. Mildly acidic groundwater has dissolved small caves and an extensive system of crevasses in the carbonate rocks of the Kaibab Formation near Flagstaff.

FEATURE 8

Location: Highway 89A, Oak Creek Vista.

Neogene-age Basalt

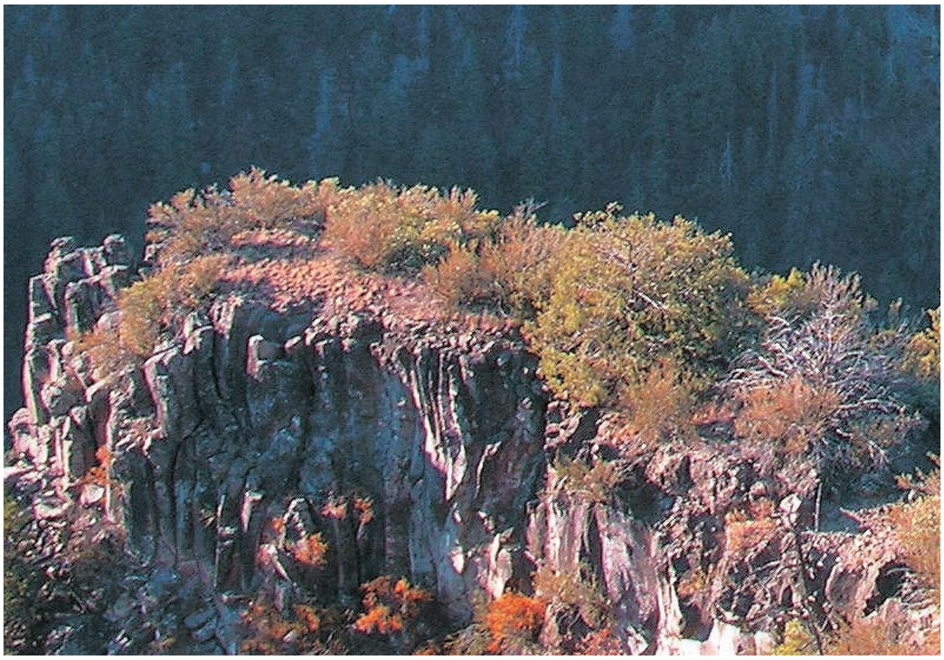


Figure 8.1 Basalt below Oak Creek Vista, Highway 89A.

Figure 8.2 Columnar jointing in basalt rimrock above Oak Creek Canyon.

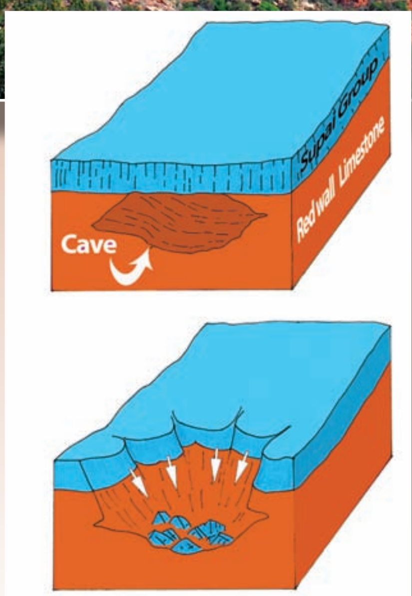
The gray- and black-colored rock (Figure 8.1) that caps the plateau at this location is basalt. It is dark in color because it contains dark iron- and magnesium-bearing minerals. The basalt originated as a lava flow from the western edge of the San Francisco volcanic field. This field contains over 600 cinder cones and covers more than 1800 square miles (4700 square km) of north-central Arizona.

This 6-million-year-old basalt was from early eruptions in the volcanic field. At a temperature of about 2,000º F (about 1100º C) the lava baked and chemically altered soils that had developed on the surface of the underlying Kaibab Formation.

Basaltic lavas are low in silica and relatively fluid. They can flow great distances from vents and fissures forming long sheets and tongues of lava.

Because the lava was in direct contact with cool rocks underneath and cool air above, it solidified and cooled rapidly. As the temperature dropped, the basalt contracted, and a network of polygonal cracks, called columnar joints formed. These cracks are typically perpendicular to the upper and lower cooling surfaces of the flow. The resulting angular columns (Figure 8.2) grace the basalt rimrock in numerous locations above Oak Creek Canyon. Devil's Postpile in California, Giant's Causeway in Northern Ireland, and Devil's Tower in Wyoming also provide dramatic examples of columnar jointing.

Geologic Features Along Highway 179 and Road 78 South of Sedona



FEATURE 9

Joints and Pinnacles

Location: From the junction of Highways 89A and 179 in Sedona, follow Highway 179 south to Chapel Road, turn left and follow the road to any of the parking areas for the Chapel of the Holy Cross.

Figure 9.1 Joints (A) and pinnacles in rocks of the Supai Group, near Chapel of the Holy Cross.

Vertical cracks in the Supai Group in Figure 9.1, A formed as the sedimentary rocks became compacted by the weight of overlying sediments, through dewatering, and as a result of stress caused by uplift after the buried sediment had been converted to brittle rock by cementation. Sets of joints intersect bedding planes (Feature 13) at nearly right angles and break the layers of sediment into blocks.

Joints are significant because chemical and physical weathering processes occur along them. Water from rain and melted snow seeps into joints and freezes during winter nights. The resulting expansion of the ice exerts sufficient pressure to shatter rock and widen joint walls. Plant roots also enter and wedge open the joints. Accumulated soil acts as a sponge, keeping slightly acidic groundwater in contact with joint walls, which decompose by chemical weathering processes.

Working in concert over hundreds of thousands of years, weathering and erosion have widened and deepened joints to form the spectacular pinnacles that are so common in the landscape of the Sedona region.

FEATURE 10

Location: Follow Highway 179 south from Sedona for 3.5 miles (5.63 km.) to Back of Beyond Road, turn right and drive 0.6 mile (.97 km) to Forest Service Trail 170. This trail will take you near Cathedral Rock. To reach the volcanic plug it is necessary to hike across rough country.

The black-colored rock pinnacle (Figure 10.1, A) projecting from the Supai Group sandstone of Cathedral Rock is a volcanic plug. About 15 million years ago molten rock (magma) rose from deep magma chambers, invaded the crustal rocks of the Sedona region, erupted from volcanic vents, and emerged onto the Earth's surface as volcanoes and lava flows. Below what is now Cathedral Rock, the magma flowed towards the surface through a long, vertical pipe and also opened and filled radial cracks blasted into the surrounding sandstone. In time, the molten rock filling the pipe and the radial cracks cooled and solidified to form basalt. The basalt-filled pipe is a volcanic plug; the basalt-filled crack is a dike (Figure 10.2).

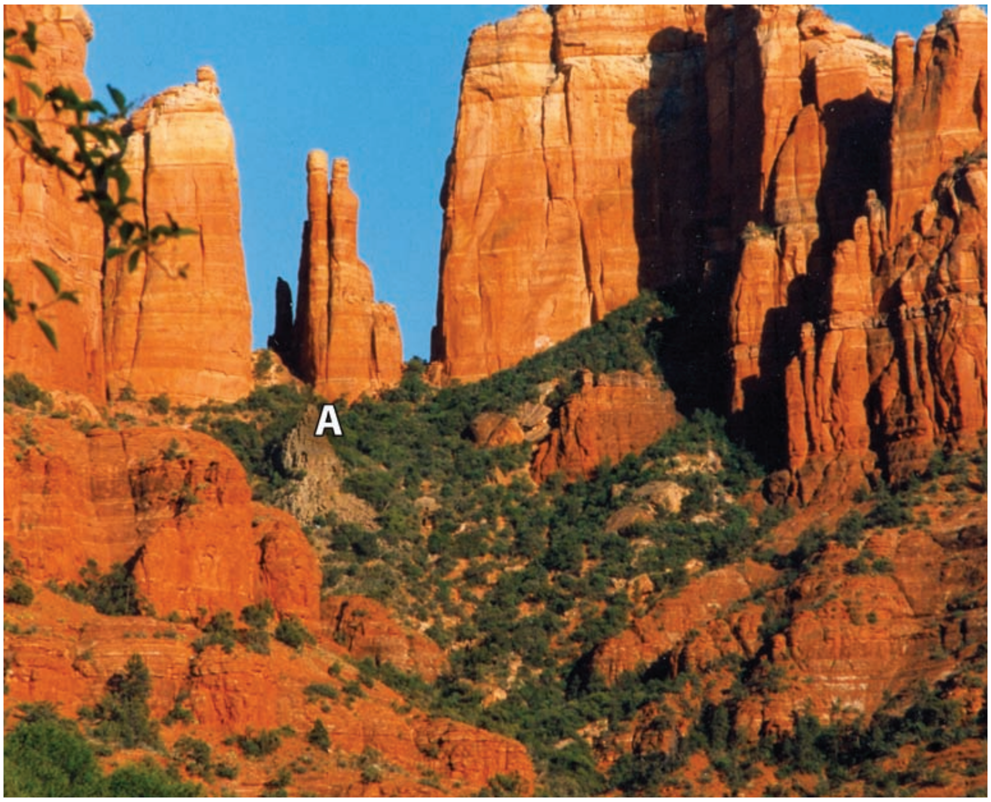


Figure 10.1 Volcanic plug (A) injected into Supai Group sandstone at Cathedral Rock. (Photo by Dr. Larry D. Fellows)

Running water has since eroded away much of surface volcanic rock and cut down through thousands of feet of sedimentary rock to the Supai Group, which forms the present ground surface. Here at Cathedral Butte, erosion has exposed the volcanic plug and one of the radial dikes. Is it possible that heat from the molten rock somehow hardened the adjacent strata that now form Cathedral Rock, and made it more resistant to weathering and erosion? If the magma reached the surface, a small cinder cone may have once existed above the top of Cathedral Rock.

Volcanic plugs and dikes are of economic interest because precious and industrial metals have been found in the recrystallized zones that commonly occur along their margins.

Thanks to Dr. Larry D. Fellows for calling this feature to our attention. He observed this feature many years ago while visiting the Red Rock Crossing and subsequently hiked up to it to confirm its composition and photograph it. The dike was earlier mapped by geologists but the plug was not.

Figure 10.2 Volcanic Dike injected into Supai Group sandstone at Cathedral Rock. (Photo by Dr. Larry D. Fellows)

FEATURE 11

Location: From the junction of Highways 89A and 179, follow Highway 179 for 1.4 miles (2.25 km.) south to Morgan Road. Turn left or east and drive 0.6 miles (.96 km) to the end of the pavement. Walk the Broken Arrow Trail for about 0.5 miles (.8 km). The tinajas are visible from the trail.

Figure 11.1 Tinajas cut into the sandstone bed of a small drainage along the Broken Arrow Trail.

The small rock basins (Figure 11.1) cut into the sandstone of this stream bed are tinajas (pronounced tee-ná-has), the Spanish word for large earthen water jars fired so that water will seep to the vessels' surface and keep their contents cool by evaporation. Tinajas or rock tanks, as they are called in English, are best formed in the bedrock channels of steep desert and mountain canyons.

Boulders, cobbles, and pebbles tumbled by swiftly flowing water during floods act as cutting tools that gouge out depressions in the underlying bedrock. The upstream sides of these enlarging depressions bear the full impact of the moving rock debris and are consequently deeper than the downstream sides, which are breached by outlet channels. Because of this asymmetrical shape, tinajas are flushed clear of organic and rock debris by flash floods and filled with water by the slower flows that follow. In dry periods, when this drainage no longer flows, these tinajas can retain a supply of clear water.

In deserts and in canyons that have only intermittent flow tinajas are critical sources of water for humans and wildlife. Some are more than 20 ft (6 m) deep and hold thousands of gallons (liters) of water months after the last rain. Please do not pollute or camp near these precious water sources.

Sinkhole

FEATURE 12

Location: From the junction of Highways 89A and 179, follow Highway 179 for 1.4 miles (2.25 km.) south to Morgan Road. Turn left or east and drive 0.6 miles (.97 km) to the end of the pavement. Walk the Broken Arrow Trail for about 0.6 miles (.97 km). The sink hole, locally called the Devil's Dining Room, is fenced and is located just to the left of the trail.

Figure 12.1 The Devil's Dining Room sinkhole.

The deep, circular depression in Figure 12.1 is a sinkhole. It is about 20 ft. (6 m.) wide and approximately 90 ft. (27 m.) to the bottom of the depression. The sinkhole is probably developed in the Redwall Limestone, which underlies the Supai Group surface rock.

After the deposition of the Supai Group, downward-moving groundwater dissolved a cave in the Redwall Limestone. When the cave grew beyond the supportive power of the limestone its roof collapsed, forming a sinkhole that is filled with sandstone and siltstone debris from the Supai Group (Figure 12.2).

Sinkholes are common features in landscapes produced by the dissolving action of groundwater on limestone, dolostone, or marble. Where sinkholes extend below the water table they hold small lakes or bogs. In northern Arizona, sinkholes in the Redwall Limestone filled with rock debris from the Supai Group and other formations are of economic interest because they contain copper and uranium deposited by mineral-rich groundwater.

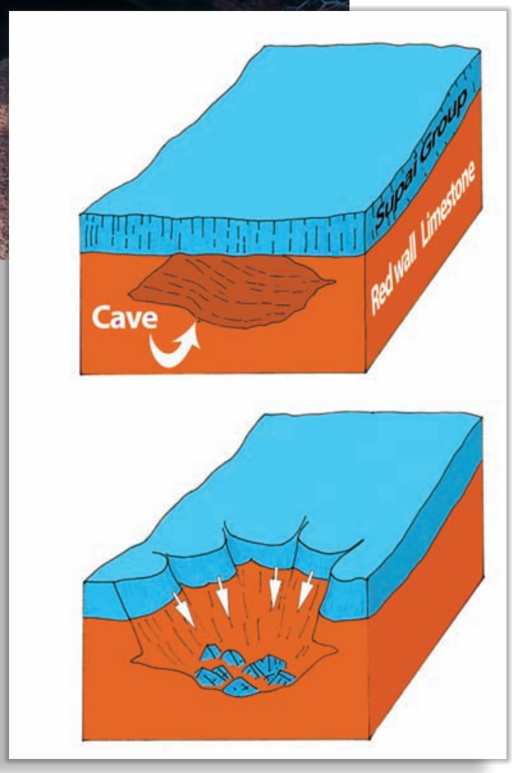


Figure 12.2 Block diagrams illustrating the formation of the Devil's Dining Room sinkhole.

FEATURE 13

Location: From the junction of Highways 89A and 179 in Sedona, follow Highway 179 south to the U.S. Forest Service interpretive exhibit, located about 0.75 mi. (1.2 km.) north of the Village of Oak Creek. Walk the 1.1 mile (1.78-km.) interpretive trail to Bell Rock.

Bedding Plane Weathering

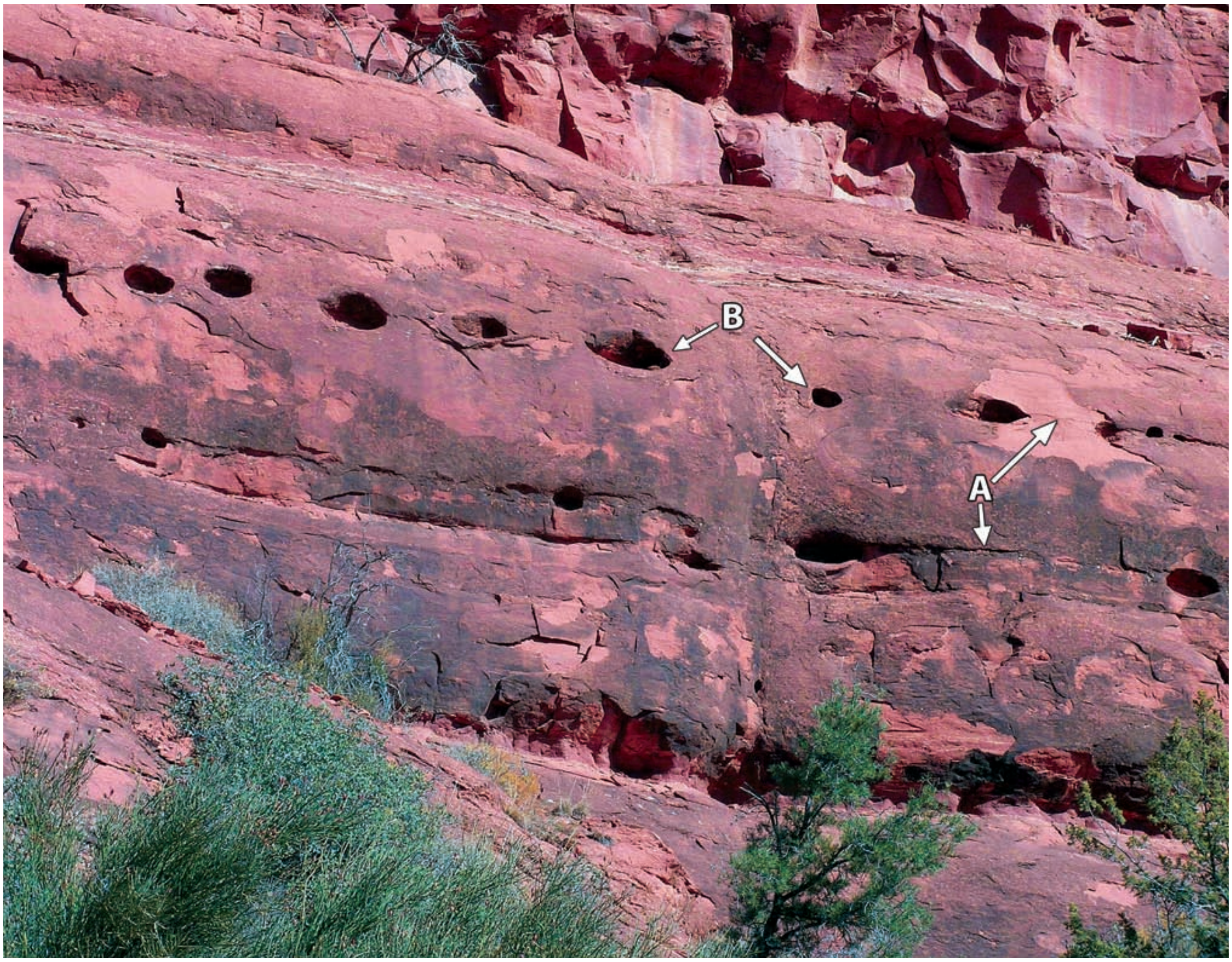


Figure 13.1 Aligned niches (B) in sandstones and siltstones caused by weathering along bedding planes (A).

The horizontal lines at A in Figure 13.1 are bedding planes that separate individual beds of sandstone and siltstone of the Supai Group. Each bed was deposited in a tidal beach environment that was slightly different than that for adjoining beds, and may also vary in grain size, mineral composition, and degree of cementation of individual sand grains. This lack of uniformity causes thinly bedded sandstones and siltstones to weather and erode more rapidly than massive sandstones such as the Coconino Sandstone (Feature 5). The reason is that bedding planes, the flat surfaces separating the compositionally different beds, are natural seams along which moisture penetrates from the surface, deep into the rock.

The holes in this cliff face (B) are aligned along bedding planes. Water percolates through porous sandstone, comes into contact with the bedding planes, and follows these surfaces to the face of the cliff. Each time the rock is wetted, moisture dissolves some of the calcium carbonate cementing together the sand and silt grains that form the sandstones and siltstones. The release of a few sand or silt grains from the cliff face produces a tiny hole that, in time, enlarges to a niche. Niches can coalesce to form alcoves (Feature 20).

Water circulating along bedding planes and joints (Feature 9) is honeycombing many of the sandstone and siltstone cliffs of the Colorado Plateau with cavernous pockets. This type of weathering dissolves the mineral cement that bonds individual grains and will eventually lead to the complete disintegration of these sedimentary layers. It is a major process in the reduction of mesas and buttes.

FEATURE 14

Location: Follow Highway 179 south from Sedona and the Village of Oak Creek to Road 78. Turn right on Road 78 and drive for about 5 miles (8 km.) for a good view of the shield volcano. To drive to the top of the volcano follow Road 78 to Forest Service Road 9952 for about 4 miles (6.45 km.) and then hike to the west-northwest for about 1.6 miles (2.8 km.).

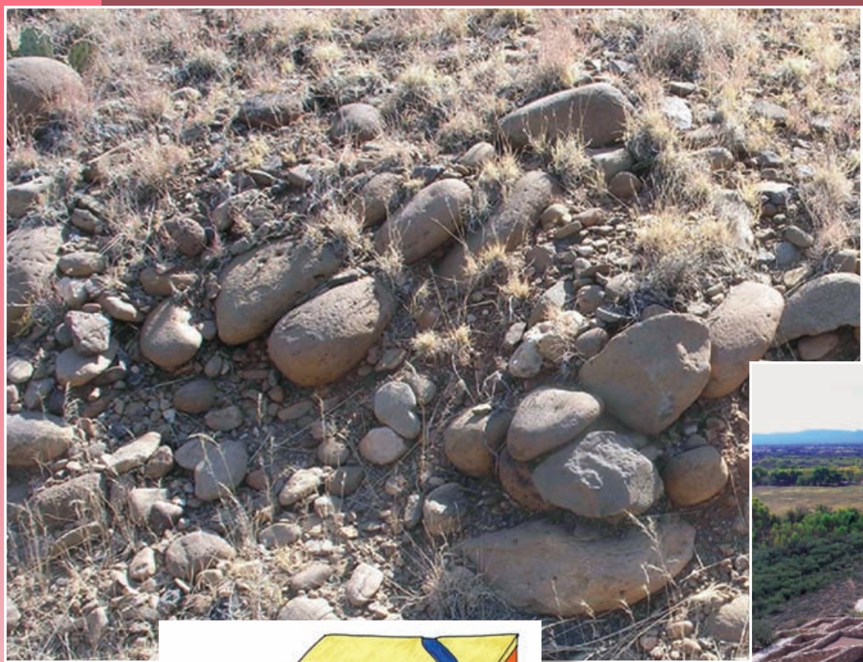
Figure 14.1 The House Mountain shield volcano.

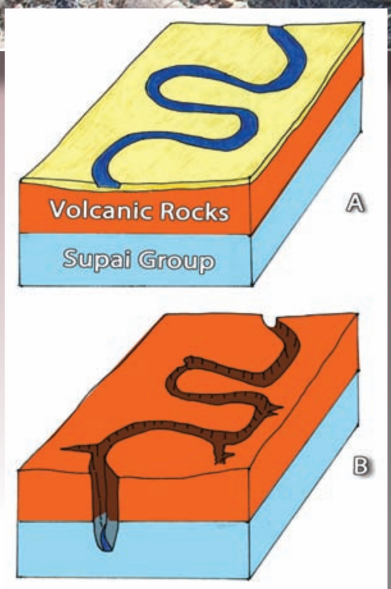
The low, dome-shaped profile of House Mountain (Figure 14.1) is typical of shield volcanoes. This volcano was built about 13 to 15 million years ago by a series of fluid (low viscosity) lava flows from a volcanic vent. Some geologists believe that the vent was located at the base of the ancestral Mogollon Rim, which allowed lava outpourings to flow in only a 180 degree arc to the west, south, and east. After eruptions ceased, the Mogollon Rim eroded to its present location, about 4 miles (6.45 km) northwest of the vent. As a result, the form of the volcano built from the successive flows is only half a cone, rather than the low circular mountain usually resulting from this type of eruption.

Although the circular summit crater has been breached and worn away by erosion, the graceful symmetry of the volcano is preserved when viewed from the south along Road 78.

The effusive eruptions associated with shield volcanoes tend to produce numerous, relatively low-volume flows that are too fluid to build volcanoes with slopes steeper than 5 to 7 degrees. Explosive, gas-rich eruptions produce fewer flows but high volumes of cinders, ash, and volcanic bombs that can support cinder cone slopes approaching 36 degrees. Small cinder cones, with a basal diameter of .6 mi. (1 km) and 200 to 300 yds (about 200 to 300 m) tall, are far more numerous than shield volcanoes in Earth's volcanic fields.

Geologic Features Along Highway 89A Southwest of Sedona





FEATURE 15

Location: Follow Highway 89A south from its junction with Highway 179 in Sedona to Airport Road. Turn left onto Airport Road and continue to the first public parking lot. Walk back down this road to the first road cut; rounded cobbles are exposed in this cut.

Figure 15.1 Sand and rounded pebbles and cobbles capping Airport Mesa.

The sand and rounded gravel and cobbles that cap this sandstone mesa were deposited about 2 to 3 million years ago by Oak Creek. The gravel and cobbles were rounded by tumbling in Oak Creek during flash floods. The stream used these rock fragments to widen and bevel the sandstone floor of its valley. Oak Creek then filled this part of the valley with over 100 ft. (30.5 m) of sediment containing the sand and rounded gravel and cobbles. Regional uplift over the last several hundred thousand years caused the stream to cut its channel down into these sediments and, eventually through over 700 feet (213 m) of sandstone to the present valley floor. This down-cutting left gravel and cobble-capped mesas, such as Airport Mesa, as high standing remnants of the former floodplain.

These floodplain remnants are testimony to the dramatic changes that occur in stream valleys over geologic time.

FEATURE 16

Entrenched Meanders

Location: Follow Highway 89A south from Sedona to Red Rocks State Park. The entrenched meanders of Oak Creek are easily viewed from the Visitor Center.

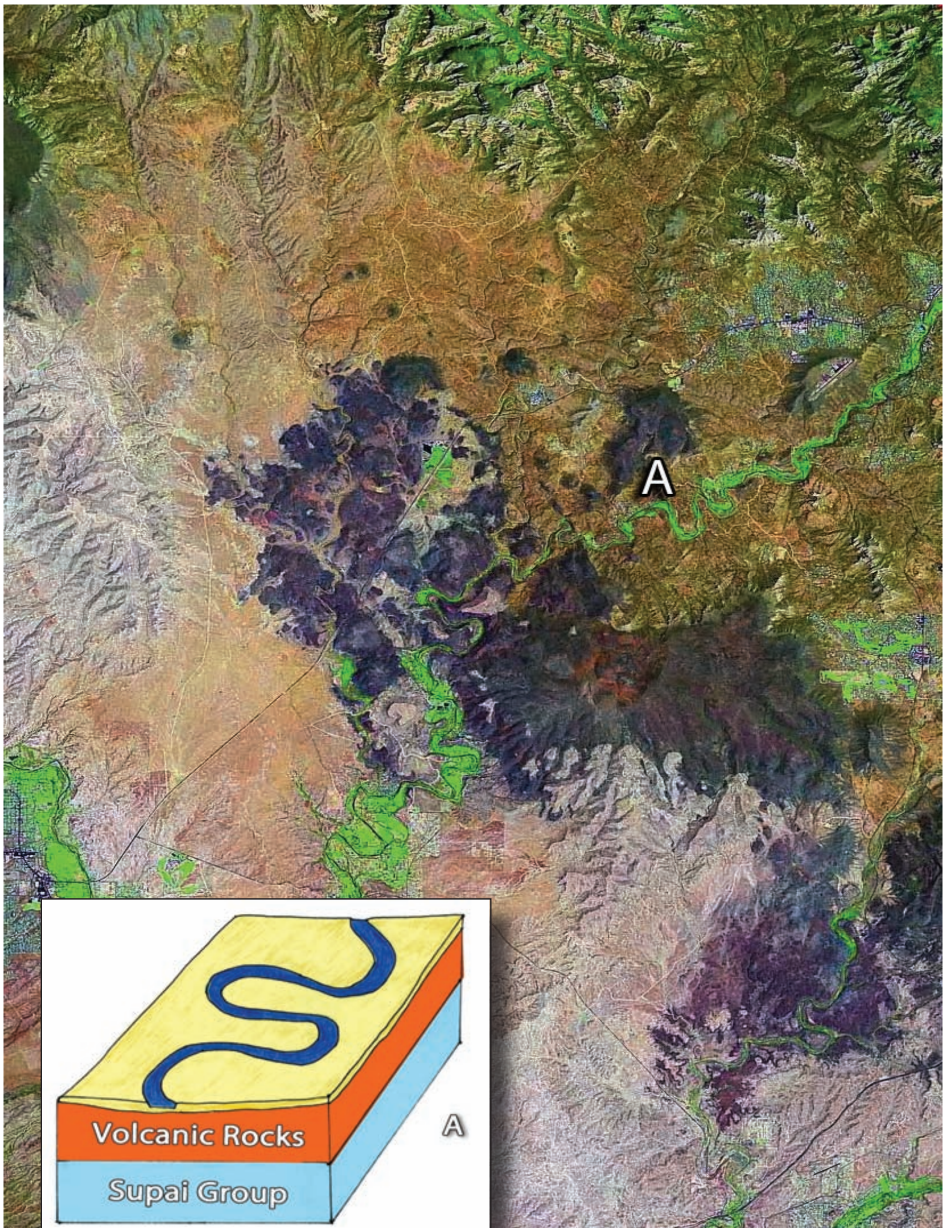


Figure 16.1 False color satellite image showing the sinuous bends in the entrenched canyon of Oak Creek (A) in the vicinity of Red Rock State Park.

The deep, sinuous bends in the course of Oak Creek Canyon (Figure 16.1, A) are entrenched meanders. A number of canyons with streams that are tributary to Oak Creek have a similar form. These entrenched meanders preserve the flow pattern of Oak Creek when it flowed along a broad, gently sloping plain. Before cutting this canyon, Oak Creek swung in broad loops, called meanders (Figure 16.2, A), across its floodplain—as does the present lower Mississippi River.

At some point, probably during the later part of the Cenozoic Era (2 to 25 million years ago), this river was no longer able to maintain its floodplain. Regional uplift of the land, combined with complex changes in stream bed slope and the quantity of sediment and flowing water, caused it to erode its own bed. Oak Creek and its tributaries maintained their original meandering courses as they cut deeper and deeper into the sedimentary rocks of the Supai Group, eventually carving a canyon containing deeply entrenched meanders (Figure 16.2, B).

Given enough time, Oak Creek and its tributaries will widen their valleys and again meander along broad floodplains.

Entrenched meanders are common on the Colorado Plateau, where meandering streams have downcut their channels into underlying sediments and, eventually, bedrock. Entrenched meanders also can be seen at Goosenecks State Park and Natural Bridges National Monuments in Utah, and in the Grand Canyon.

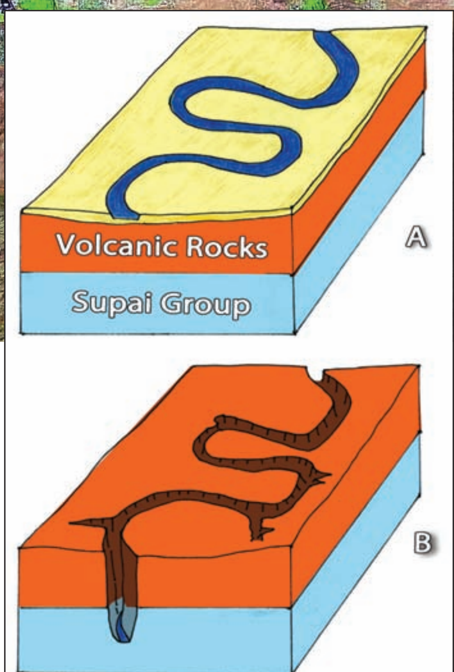


Figure 16.2 Block diagrams illustrating the formation of entrenched meanders.

FEATURE 17

Location: Follow Highway 89A south from Sedona to mile post 356.5.

Figure 17.1 Limestones of the Verde Formation exposed along the Verde River Valley.

The light-colored rocks exposed in the hill in the middle-ground of Figure 17.1 are fresh-water limestones of the Verde Formation. This formation was deposited between 7.5 and 2.5 million years ago (Miocene-Pliocene time) in large, shallow lakes and marshy environments in the broad basin now drained by the Verde River. During this time period, the Verde River was dammed by faulting and volcanic eruptions and could not flush accumulating clay, silt, sand and volcanic ash from the enclosed basin. Over 3,000 ft. (914 m.) of these sediments, interbedded with limestone, gypsum, and rock salt left behind by the evaporation of lakes, eventually filled the subsiding basin. Mineral-rich springs also deposited extensive travertine (calcium carbonate) deposits on and within the Verde Formation.

About 1 million years ago the Verde River breached the natural dams and downcut its course through the Verde Formation, integrating its drainage with that of the Salt River. As a consequence, this stream erosion has exposed layers containing rich fossil assemblages ranging from aquatic plants and animals to mastodon and three-toed horse.

FEATURE 18

Location: Follow Highway 89A south from Sedona through the town of Cottonwood to Dead Horse State Park. Drive the park road to Roadrunner Road, turn left and follow this road to the Blackhawk Loop of the campground.

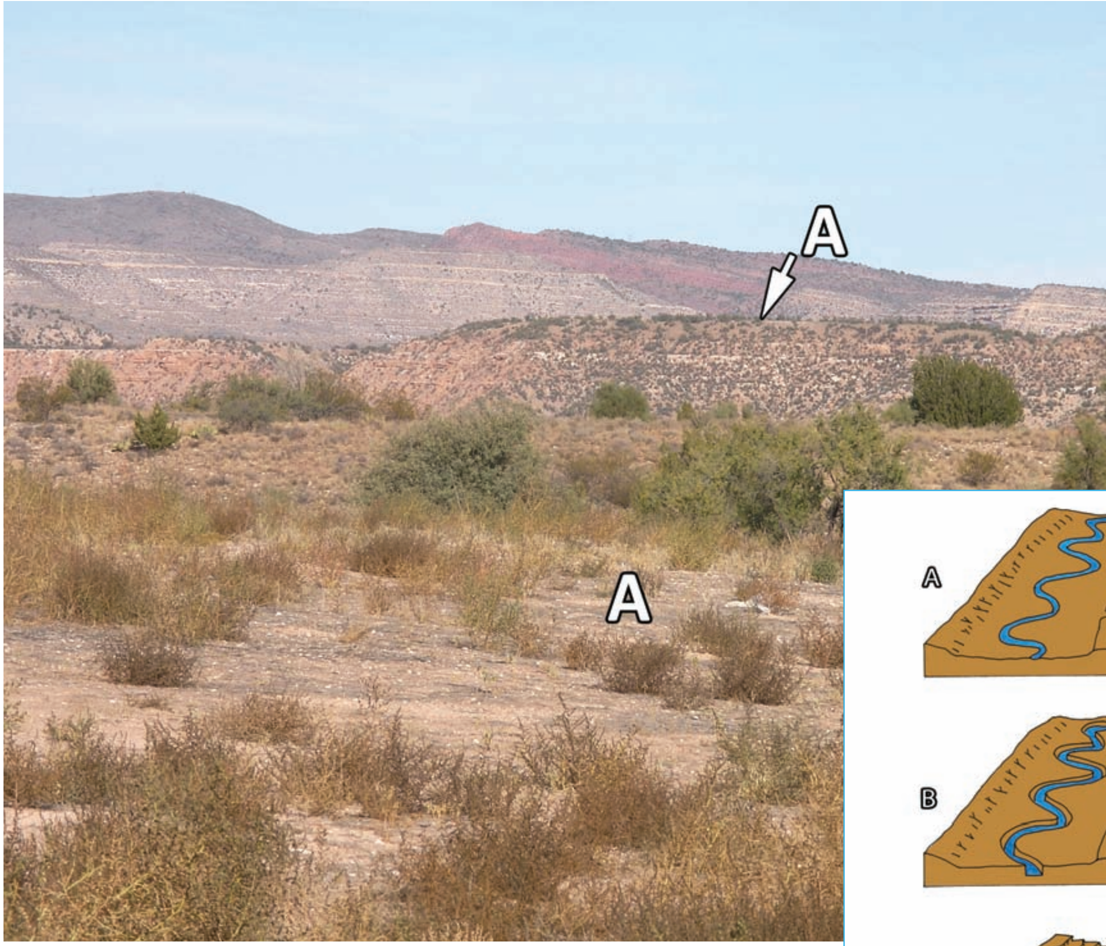


Figure 18.1 Stream terraces (A) along the Verde River at Dead Horse Ranch State Park.

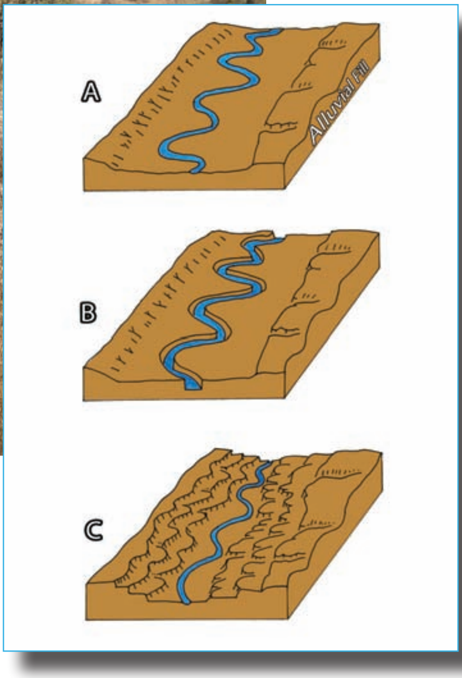


Figure 18.2 Block diagrams illustrating the formation of stream terraces. A) The Verde River cuts a valley and floodplain into alluvial fill. B) The river downcuts its bed into the sediment previously deposited along its floodplain. C) Repeated cycles of cutting and filling by the river produces step-like terraces along the margins of the valley.

The flat, step-like surfaces at points A in Figure 18.1 are stream terraces. Terraces are constructed of silt, sand, pebbles, and cobbles that were deposited by running water. Tumbling in a stream during flash floods rounded the pebble- and cobble-sized rock fragments on the ground at your feet.

Stream sediment deposits were once much thicker in this area. Over the last several tens to hundreds of thousands of years, however, the Verde River began to erode its valley into the underlying volcanic and sedimentary rocks (Figure 18.2, A). Lateral migration and deposition by the river built a floodplain on the floor of the valley. Later, the river cut its channel downward into the floodplain (B), leaving remnants of the former valley floor as high-standing stream terraces. Repeated episodes of sediment deposition and downcutting have produced a series of terraces (C) along the Verde River that is visible from this vantage point.

Stream terraces stand above the flash flood zones of valleys and have long been preferred locations for human settlement, agricultural fields, roads, and railroads.

Downcutting and channel backfilling can be triggered by alternating dry and wet climatic conditions, draining and filling of a valley by lakes, and by regional tectonic uplift and subsidence. These conditions cause variations in the quantity of water and rock debris that moved down the Verde River during the last several hundred thousand years.

Entrenched cut-off meander loop

FEATURE 19

Location: Follow Highway 89A south from Sedona through the town of Cottonwood to Tuzigoot National Monument.

Figure 19.1 Tuzigoot pueblo was built on an entrenched cut-off meander loop eroded by the Verde River.

The outcrop of Verde Formation limestone occupied by the ruins of Tuzigoot pueblo was once attached to the long bedrock ridge in the distance (Figure 19.1A). The Verde River eroded the cut at point B, isolating this rocky strong point from the limestone margins of the valley.

This type of landform is an entrenched cut-off meander loop, a name that is descriptive of the process that formed it. At one time the Verde River flowed in broad loops, called meanders, along a broad floodplain. About 1 million years ago, complex changes in drainage caused the Verde River to down-cut its bed into the floodplain and the bedrock below, preserving the meander loops in a sinuous canyon (see Feature 16). Here at Tuzigoot, the Verde River undercut opposite sides of the long neck of bedrock bordered by a particularly tight loop of its course (Figure 19.2A). Continued erosion merged the undercuts and the river shortened its course by cutting a breach through the neck, leaving the detached part of the neck as a hill protected on all sides by the former and current bed of the river (B).

For hundreds of years people have built fortified positions, such as Tuzigoot and some of the great castles along the Rhine River, on entrenched cut-off meander loops. Such sites illustrate how geologic features influence human settlement patterns.

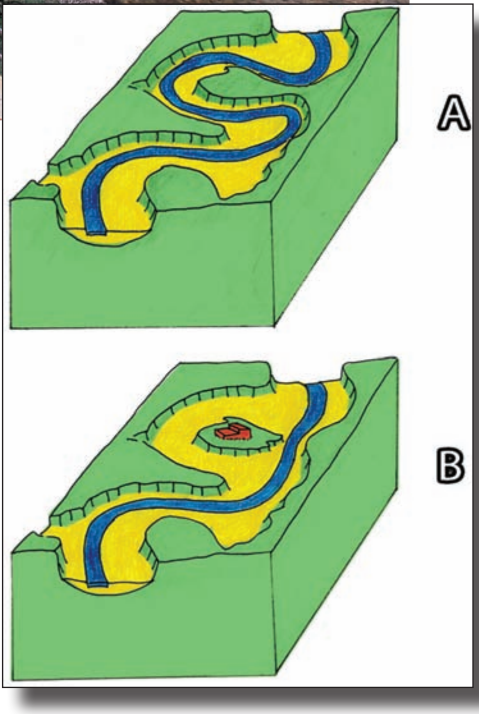
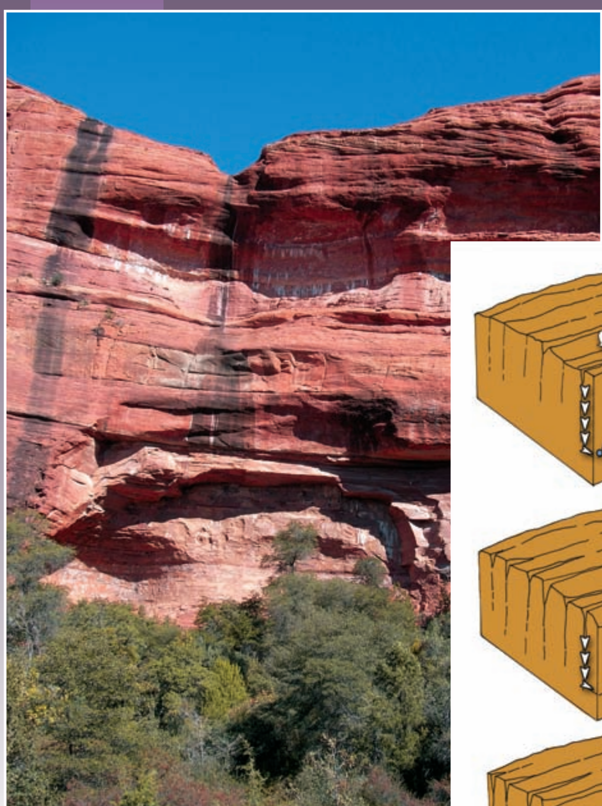
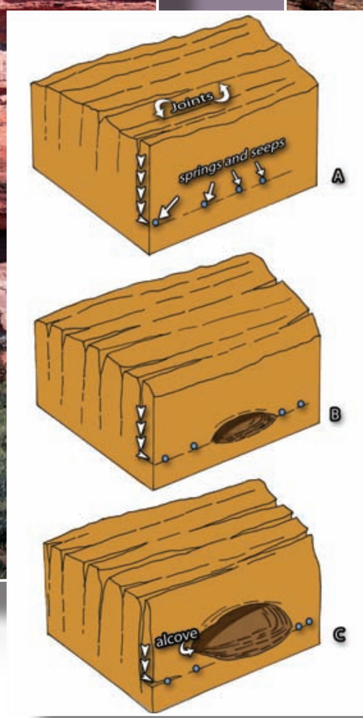


Figure 19.2 Block diagram illustrating the formation of the entrenched cut-off meander loop at Tuzigoot National Monument. Tuzigoot Ruins is the red-colored structure.

Geologic Features Along the Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 Northwest of Sedona





FEATURE 20

Location: Follow Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 to Palatki Ruins. The case hardening is on a sandstone face to the right of the ruins.

Figure 20.1 Case hardened sandstone face near Palatki Ruins.

This rock face in Figure 20.1 and that of many other sandstone cliffs in the region have developed a protective mineral rind from a process called case hardening. This rind consists of a durable film of amorphous (lacking an orderly crystal form) silica that has been drawn from the interior of the rock and re-precipitated on the surface. Although silica is not very soluble in water, small quantities of this mineral are leached from the sandstone each time the rock is wetted by rain or dew. When the moisture evaporates, the silica is deposited on the surface of the rock. While the surface of the rock is hardened by the buildup of silica, the interior is progressively weakened by the removal of that mineral.

Case hardening protects rock surfaces from chemical weathering and low energy erosion. Once this protective film is broken, as it has been along this rock face, the softer, weathered zone is exposed to the elements and disintegrates quickly.

FEATURE 21

Location: Follow Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 to Palatki Ruins.

The large opening in the cliff in Figure 21.1 is an alcove. Alcoves are ubiquitous features in sandstone cliffs throughout the Southwest and commonly contain prehistoric Indian ruins such as Palatki.

Alcoves usually develop in sandstones containing parallel sets of deep cracks, called joints, that divide the rock into vertical plates (Figure 21.2A). Slightly acidic water from rain and snowmelt runs down the joints until it encounters a bed of low permeability. The groundwater then follows that bed to the sandstone cliff where it emerges as seeps and springs. Wetting by seeps and springs dissolves the calcium carbonate or silica cement that bonds the individual sand grains into rock, causing the sandstone to crumble into sand which is then swept away by wind and rain. Also, the evaporation of moisture from the seeps and springs leaves behind small crystals of halite, calcite, and gypsum that grow and break apart the sandstone grain by grain. Repeated freezing and thawing of near-surface moisture also contributes to disintegration of the rock. In time, a niche (B) forms along the zone of seepage and springs.

As weathering increases the size of the niche, its roof develops small arch-shaped, gravity induced stress fractures. In time, the roof rock breaks under its own weight along these fractures and large slabs of sandstone fall to the floor of the expanding opening. The repeated growth of parabolic stress fractures parallel to the roof of the opening, followed by slab failure, eventually produces a large curved-roof alcove (C). The dissolution of sandstone cement along seeps and springs and slab failure, acting in concert, are important weathering processes that undermine cliffs and reduce plateaus to mesas and buttes.

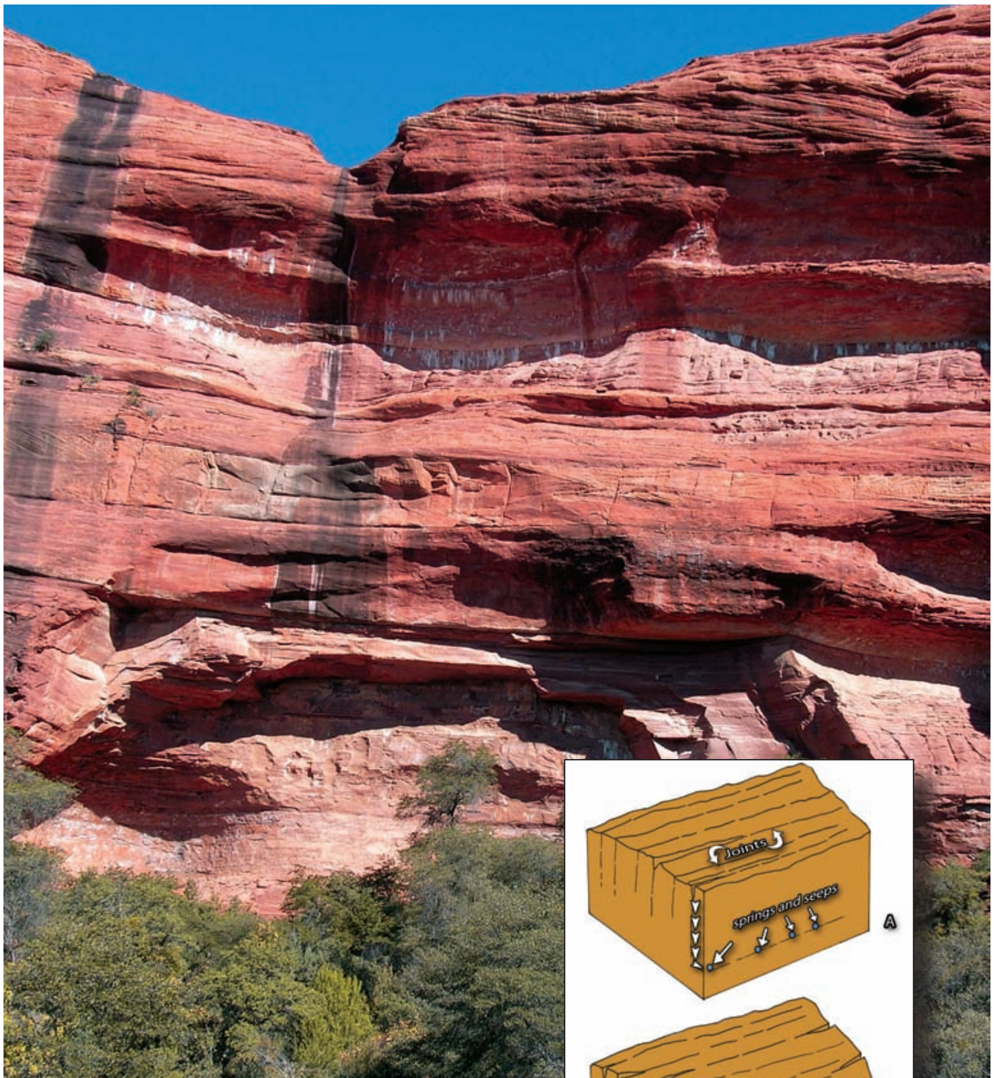


Figure 21.1 Alcove developed in Supai Group sandstone at Palatki Ruins.

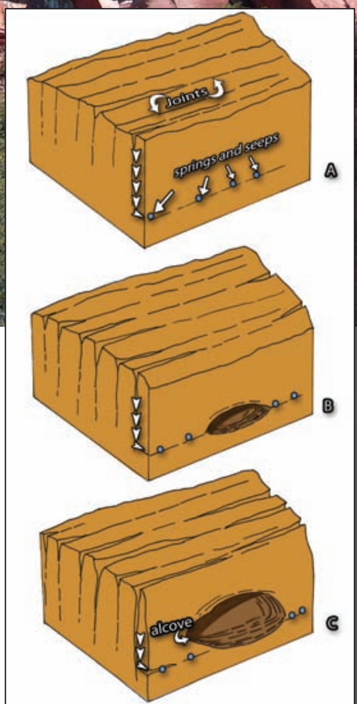


Figure 21.2 Block diagrams illustrating the formation of alcoves.

FEATURE 22

Location: Follow Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 to Palatki Ruins. Walk the trail toward the pictographs. The fallen slab of sandstone is along the same rock face that contains the pictographs.

Figure 22.1 Rock slab separated from cliff of Supai Group sandstone near Palatki Ruins.

The great, fallen slab of rock in Figure 22.1 is the result of weathering, joints, and the pull of gravity. Groundwater from rain and snowmelt percolates through the relatively porous sandstone and emerges at the base of the cliff, as springs and seeps in some locations. Over time this moisture dissolves the cement bonding the sand grains together, causing the sandstone along these basal zones to disintegrate. Repeated freezing and thawing of near surface moisture also weakens the rock. Where sandstone cliffs are undermined by this type of weathering, great slabs of rock separate along joints from the cliff face and topple to the ground below. The impact commonly breaks the fallen rock along bedding planes, making it easier for weathering processes to reduce the rock to sand. Somewhere the sand will again come to rest, forming a new sandstone or other sedimentary rock, until the cycle is repeated.

Slab failure is an important process in cliff retreat and valley-widening in the Southwest.

FEATURE 23

Location: Follow Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 to Palatki Ruins. Walk the trail to the pictographs. The mineral-stained joints are located along the same rock face that contains the pictographs.

Figure 23.1 Mineral-stained joint near pictographs at Palatki Ruins.

The brown and black mineral stains on this sandstone face are iron oxides deposited by ground water flowing from the joint (natural crack) at A in Figure 23. Slightly acidic water from rain and snowmelt that percolates down through porous sandstone also dissolves minerals from the rock. The percolating groundwater will eventually encounter joints and flow along their surfaces to the exterior of the sandstone where it emerges as springs and seeps. In periods of lower flow, the water moves in a thin film along the rock surfaces adjacent to the seep, where it evaporates and deposits those minerals carried in solution. Various iron compounds impart browns, blacks, yellows, and reds to the sandstone and, together with rock varnish (see Feature 6), mask the true color of the rock.

FEATURE 24

Location: Follow Forest Service Roads 152 (Dry Creek Road), 152C, 795 and 525 to Honanki Ruins. The cross-bedding is in the sandstone cliff above Honanki Ruins.

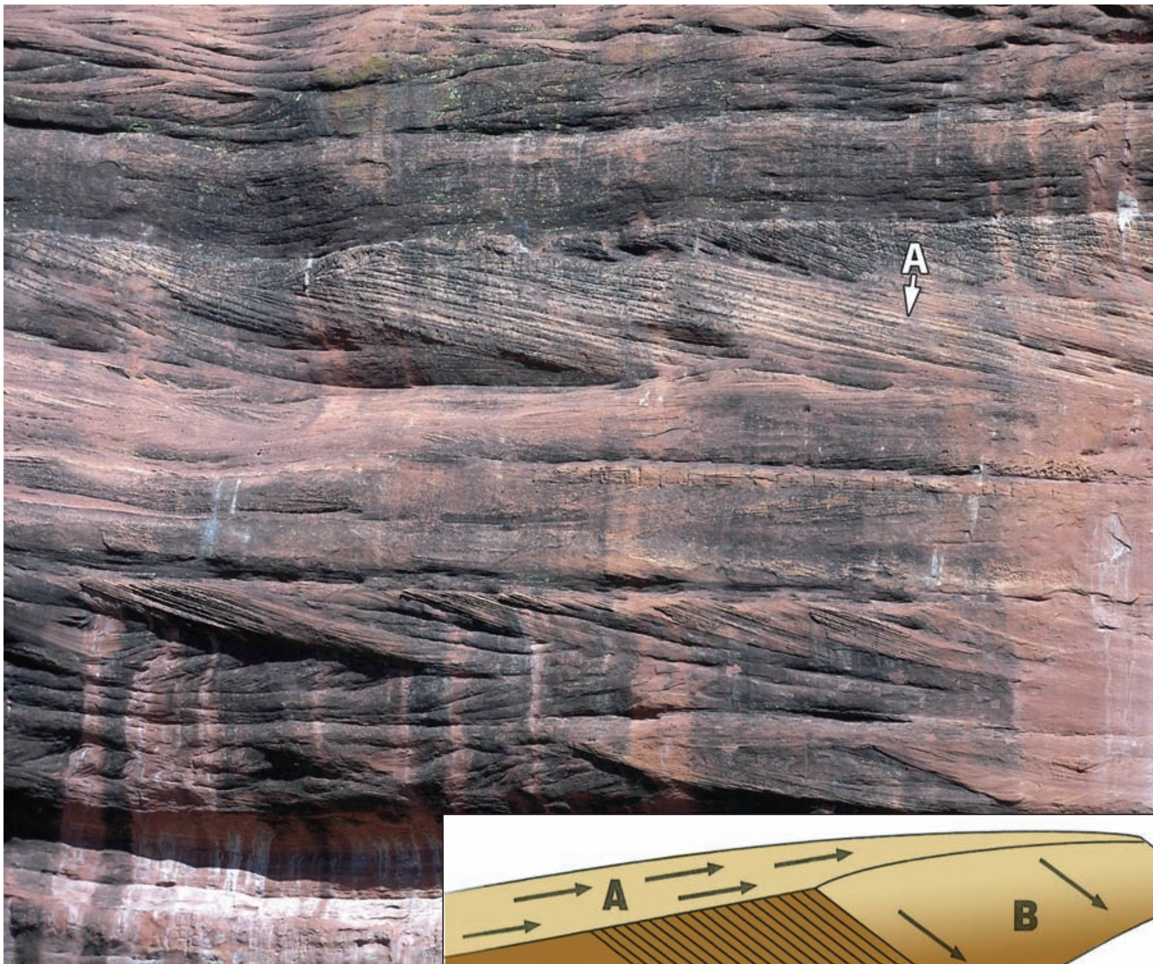


Figure 24.1 Cross-bedding in sandstone cliff, Honanki Ruins.

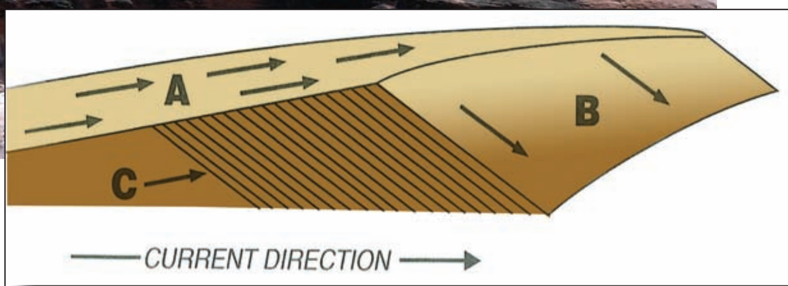


Figure 24.2 Block diagram illustrating the deposition of cross-beds in a dune or sand bar.

The tan-colored sandstone in this cliff (Figure 24.1) is part of the Supai Group and was deposited along a stream bed by running water or along a beach by waves. The thin, inclined layers in this sandstone at point A are cross-beds. These beds form as loose sand grains move across the gently sloping upstream side of a sand bar or beach ripple (Figure 24.2 A), and avalanche down the steep, downstream side (B). As inclined layers are added to the downcurrent side (C), the bar or ripple advances downstream. After these beds were buried by younger deposits, they were compacted and cemented by calcium carbonate to form sandstone. Later, erosion exposed the sandstone along this cliff.

Cross-bedded layers also accumulate in the same manner by wind movement on the leeward side of sand dunes, which are also preserved as sandstone (see Figure 5). Geologists use several clues to distinguish wind-deposited sandstones from those deposited by running water. These clues include: 1) very large cross-bed sets (often exceeding 10 ft [more than 3 m] in thickness), 2) thin, inclined layering (lamination) that forms from the migration of wind ripples, and 3) tracks and trails of insects and scorpions.

Cross-bedding can be used to determine the direction and strength of ancient wind and water currents and to estimate minimum water depth and dune height.

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Palatki Ruins

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John V. Bezy

John earned a Ph.D. from the University of Arizona, taught at several Southwestern colleges, conducted geological studies with State and Federal agencies and the private sector, and authored numerous publications about the human and natural history of the Southwest and northern Mexico. John has now authored or co-authored ten Down to Earth texts. He has worked with the potters of Mata Ortiz for many years and conducts educational tours to Mexico and other parts of Latin America.

Stratigraphic Column of the Verde Valley